Application of SAILRAIL Technology to the Transit Industry

Prepared for

Transport Canada

Transportation Development Centre

By

UTDC Research and Development Ltd.

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APPLICATION OF
SAILRAIL TECHNOLOGY
TO THE TRANSIT INDUSTRY

FINAL REPORT

TO

DEPARTMENT OF SUPPLY AND SERVICES

PREPARED FOR THE TRANSPORT CANADA - TRANSPORTATION DEVELOPMENT CENTRE

BY UTDC RESEARCH & DEVELOPMENT LTD.

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17 Abstract

The concept of marrying compliant air bearing technology with Linear Induction Motor (LIM) in track technology to create a new transportation product (SailRail) was examined from a market perspective and an engineering feasibility perspective.

The existing competition in the low-capacity people mover market was surveyed in terms of performance and cost. Additionally two application examples were examined to determine criteria for the engineering study.

Using one application scenario the product was evaluated in terms of operational performance, requiring evaluation of vehicle design, guideway design, and operating system design. Additional questions such as curving and crossovers were examined.

The study concludes that the concept provides the potential for high quality, low cost mobility and in addition a new potential market application was discovered which is not served by existing products.

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17. Résumé

Ce rapport concerne l'étude de marché et de faisabilité technique d'un concept combinant la technologie du coussin d'air au moteur linéaire à induction sur voie de guidage (SailRail), pour réaliser un système de transport tout à fait inédit.

Il présente le résultat d'une enquête sur les divers matériels qui occupent le marché des transports hectométriques de faible capacité, dont il donne les caractéristiques techniques et le coût. Il traite aussi de deux applications dont les paramètres de fonctionnement ont pu être déterminés pour les besoins de l'étude.

Prenant l'une de ces applications comme exemple, l'étude a évalué le concept sur le plan des performances globales, en procédant à l'évaluation du véhicule, de la voie de guidage et des systèmes. Deux autres aspects de la question ont également été abordés: l'inscription en courbe et les liaisons de voie.

L'étude montre que le concept envisagé possède le potentiel d'un système de transport de qualité élevée et de faible coût et qui, en outre, ouvre le créneau d'une utilisation neuve encore inoccupée par un matériel quelconque.

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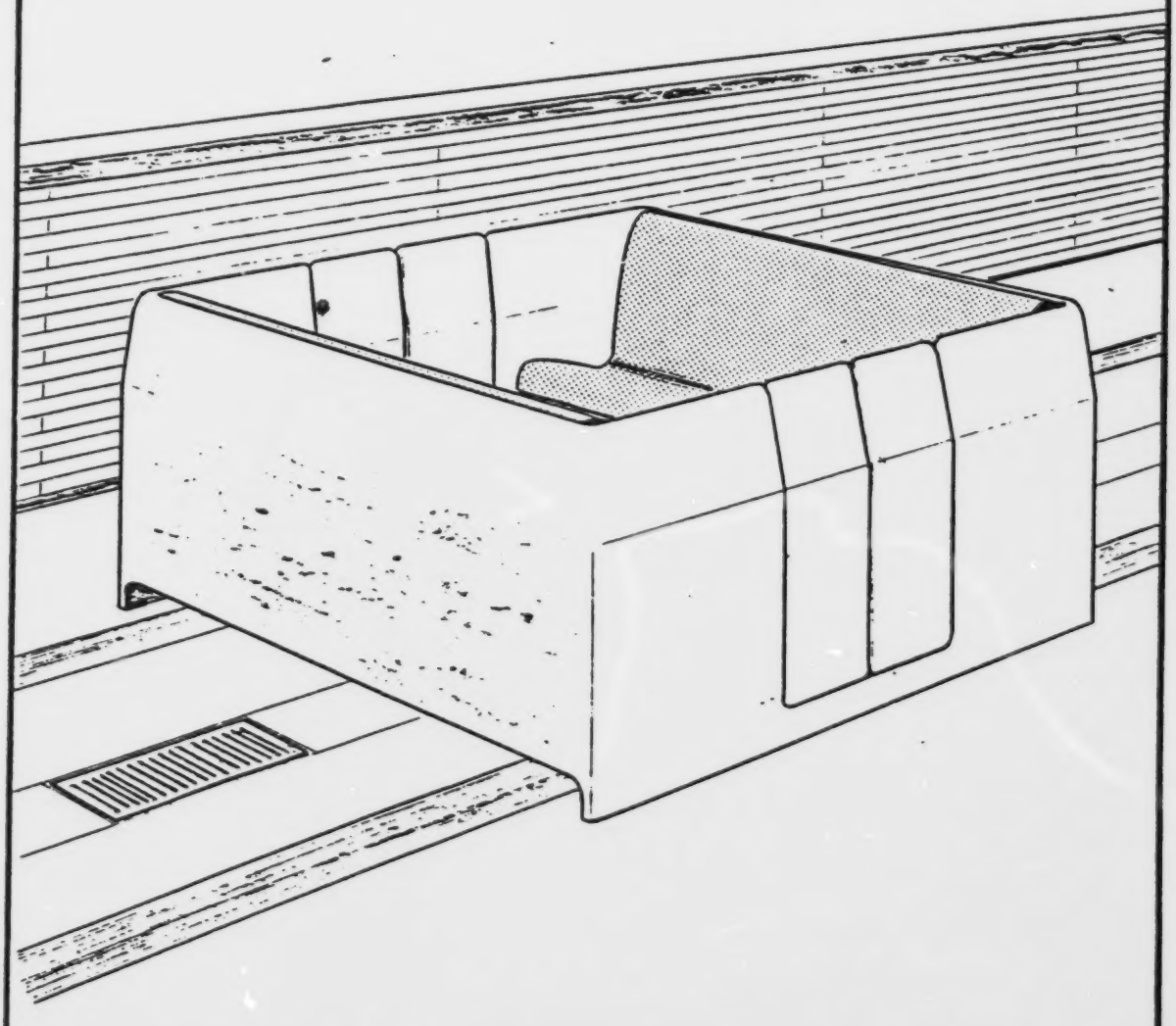
SAILRAIL TECHNOLOGY APPLICATION TO THE TRANSIT INDUSTRY



1.0 INTRODUCTION

With significant assistance from the Transportation Development Centre, the Department of National Defence, and the University of Toronto Institute for Aerospace Studies, E.B. Eddy Forest Products Company of Canada developed and tested compliant air-bearing technology for application to the material-handling industry. On 27 January 1983, the Department of Supply and Services approved a UTDC Research & Development Ltd. unsolicited proposal to conduct a preliminary study of the potential application of this technology concept in the transit industry.

2.0 OBJECTIVES

2.1 The program scope of work involved:

- a market review to determine possible application opportunities and likely operational requirements. Toronto International Airport and Expo '86 were identified as market applications that would be considered;
- an engineering study to determine preliminary system configurations and a general operating scenario of the system including order of magnitude cost estimates.

2.2 This report provides the information to meet the established program deliverables which are:

- to identify potential specific market applications for the technology, and evaluate alternative transit systems that are used or under consideration in these markets;
- to identify a system configuration and operating scenario of a compliant air-bearing system that would move people at low speeds;
- to identify the order of magnitude costs for development of the system concept.

2.3 The Study

The preliminary study of SailRail Technology Application to the transit industry is divided into two major sections. The marketing area is reviewed in depth in section 3.0 and the systems configuration and product are reviewed in section 4.0. Each section includes a cost review. Results, conclusions and recommendations are included in the following sections.

3.0 THE MARKET

3.1 Purpose

The purpose of the market review is to determine whether a compliant air-bearing (CAB) system can meet the requirement of powered specialized passenger-movement markets and whether the system can offer service and/or cost advantages in comparison to existing systems.

The following systems:

- identify and describe potential markets;
- identify and describe competitive systems;
- identify the operating requirements of two specific sites.

CAB cost information, for purposes of confidentiality, has been supplied in a separate document.

3.2 Potential Markets

Initial technology indications are that the system can transport vehicles weighing approximately one tonne at speeds approximating 25 km/h. On the basis of technological information, the low-capacity, low-speed passenger transportation market demand has been reviewed. This market can be divided into three relatively distinct markets:

1) Intra-Building
2) Inter-Building
3) Recreation

Table 1 summarizes the major operating characteristics, estimated market size, based on cursory analysis, system price, and current major suppliers for each of the three market segments. The following sections provide:

- a market description for each market segment;
- market characteristics;
- market requirements for a transit system;
- market size and outlook.

3.2.1 Intra-Building

3.2.1.1 Market Description

These markets can be defined as large single facilities within which large numbers of people traverse horizontal distances of a magnitude such that a mobility system would offer time-saving or comfort benefits when compared to walking. Such markets include:

TABLE 1
LOW-CAPACITY LOW-SPEED PEOPLE MOVERS

	INTRA-BUILDING SYSTEMS	INTER-BUILDING SYSTEMS		RECREATIONAL SYSTEMS
		"Simple"	"Complex"	
Operating Characteristics				
Capacity pphpd		500-5000	3000-10000	500-4000
Speed km/h	5	30	40	15
Station Spacing m	100-500	300-1500	300-1500	1000-5000
Guideway Environment	Indoors, on floor	Open or protected, elevated or tunnel	Open or protected, elevated or tunnel	Open-Elevated
Market Size				
Passenger Places per Year	(1) 5000	400	250	500
Basis of Estimate	Estimate by analogy with Elevator/ Escalator markets	Historical trend	Historical trend	Historical trends
Market Price per Passenger Place	$10,000-$50,000	$40,000	$100,000	$25,000
Annual Market $	$62.5M	$16M	$25M	$12.5M
Products				
Dominant Supplier	None	Westinghouse	Westinghouse	Unimobil
Other Suppliers	Several moving walk -way manufacturers	WEDway VSL	ICTS	WEDway

(1) This market has not been developed and therefore the projected market size is an unsubstantiated estimate.

- Airports: In airports, a network of corridors connect gate areas with luggage retrieval and general airport access areas, all within the same terminal. Incoming and outbound passengers and those making flight connections often must traverse significant distances with luggage and packages.

- Convention Centres: Modern convention centres contain extremely large open areas to facilitate the display of hundreds of exhibits. Customers and visitors are required to traverse significant distances to view the various displays and to travel throughout the building.

- Shopping Malls: Many shopping malls are so designed that two or more large department stores are connected by one or more interior corridors. These corridors act as an access to many smaller stores that lie between the larger stores. This design results in large people flows in the corridor areas.

3.2.1.2 Market Characteristics

- At present the markets identified above are served only to a limited extent by moving sidewalks.

- The market is such that almost immediate access to many points within the large facility must be easily available.

- Public safety as regulated by Federal, Provincial/State, and Municipal governments dictates that exit capabilities be maximized in this type of market area.

- The facility size and design offer the opportunity to reach any point within the facility by walking.

3.2.1.3 Market Requirements for a Transit System

- Operation must be totally inside.

- Distances between stations must be very short.

- Loading/unloading methods must be simple to accommodate the elderly, the handicapped and young children; normally at-grade stations are required.

- People must be able to frequently pass over or across the guideway.

- Structures must be aesthetically acceptable and blend with the environment.

- Passengers must have complete visibility of nearby surroundings.

- The system travel time must be less than walking and offer a comfortable, safe ride.

3.2.1.4 Market Size and Outlook

There is currently no widely affordable product in this market. Battery-powered, rubber-tired golf-cart type trackless vehicles are sometimes used at airports and large factories for internal movement in the 100 m to 1000 m range; however, they are too costly to operate for any significant volume of traffic. An example is the service provided by Air Canada at Toronto International Airport for the elderly and disabled.

Moving sidewalks carry high continuous volumes; however, their application is limited because of high costs for the equipment and operating maintenance, and perhaps most significantly, the structural and spatial requirements for installation. Existing moving sidewalks require special structural support and machinery pits. Furthermore, they constitute a barrier to pedestrian circulation across the sidewalk.

If a horizontal people mover could be developed that carried moderate volumes of people (say 500 people per hour per direction (pphpd)) at an average speed faster than walking, without requiring costly building structural modifications and without creating an unacceptable barrier to other pedestrian traffic, there is a potentially large market, assuming that building owners wish to provide horizontal transfer service comparable to vertical transfer service (escalators).

3.2.2 Inter-Building Markets

3.2.2.1 Market Description

These markets can be defined as locations consisting of two or more facilities between which large numbers of people will travel. The travel distance is either beyond the normally accepted distance for walking, or of sufficient length that a transit system could provide time-saving and significant comfort benefits. Such markets include:

- Shopping Malls: Yorkdale Mall in Toronto is an example of large shopping facilities where much of the parking space is located a considerable distance from the shopping facility itself. The opportunity to transport shoppers between the building(s) and parking lots is a market in itself. The shopping malls may also need to be connected to other major points such as railways and bus terminals.

- Airports: A great many airports such as Toronto International Airport are divided into two or more terminals, each terminal containing its own separate parking facilities. In many cases, hotels are located in an adjacent area and car- leasing companies have buildings and storage space at the periphery of the airport. Large numbers of people must transfer between the above-described separate facilities; this creates a significant transit market.

- Residential Complexes: The concept of small, completely self-sufficient residential areas within urban environments is rapidly gaining popularity. Las Colinas, near Dallas, Texas, is an example of this type of complex. To provide fast and easy access to all major points within the complex, some type of transit system is required.

3.2.2.2 Market Characteristics

- Competitive transit systems already serve a number of airport locations. The other markets identified above are basically new markets not served by transit systems.

- The market location may or may not allow walking as an alternative.

- High reliability and frequent service are prime requirements.

- Passenger volumes will vary significantly during hourly and daily periods.

3.2.2.3 Market Requirements for a Transit System

- Inside and outside operation.

- Short headways.

- Short trip times with rapid velocity between points (25-40 km/h).

- Normally, elevated guideways will be required. Underground guideways may be required.

- High availability, reliability, and comfort will be major requirements.

- Storage space for luggage and parcels will be required on the vehicles.

3.2.2.4 Market Size and Outlook

This market can be divided into locations that need only systems with simple operating capabilities and locations that require systems with more complex operating capabilities.

o Simple Inter-Building Systems

Several simple inter-building systems have been built in the last decade, mostly at airports. Some are straightforward shuttles, without switching or curves. Tampa Airport is the premier example. Seattle-Tacoma, Houston, Miami, Bradley, and Orlando airports, Disneyland, Disney World, and Seattle monorails, VSL-Las Vegas, Fairlane, and Pearl Ridge add curves. Bradley Airport (now closed) also required switching at a mid-line passing track. Although some of these systems are installed in tunnels, the technologies are generally capable of all-weather, outdoor operation. Heating and air conditioning are usually provided on board vehicles.

The market for these "simple inter-building" systems has averaged approximately 400 passenger-places per year over the last decade. Future markets for "simple inter-building" systems include Las Colinas, South Coast Plaza, and numerous other mostly suburban parking- lot-to-building and building-to-building applications. While air travel growth as a whole has slowed, medium-sized airports are still growing and several can be expected to require satellite terminal or remote parking lot connections in the next decade.

Westinghouse has dominated this market. Disney's WEDway has recently been installed in Houston, and will probably be highly competitive for future simple, inter-building applications. Note that although WEDway is capable of all-weather operation, no system with vehicle heating or air conditioning has been installed. For short, mostly level and tangent, alignments, cable-propelled systems such as the VSL-Shuttle constitute significant, low-cost competition. Three Alweg-Disney monorail systems have been installed, two at Disney's own theme parks, connecting remote parking lots and hotels.

o Complex Inter-Building Systems

Only a few complex inter-building systems have been built in the last decade. Besides curves, grades, switching, and all-weather outdoor operation, these systems involve multiple routings and close headways. The two most complex systems, Air Trans at Dallas Fort Worth Airport and the Morgantown system, have been plagued with technical problems, especially in command and control. A third system, at Atlanta airport, although weather-protected and tangent, operates successfully with close headways and multiple crossover and turnback routings. The Miami and Detroit Downtown People Mover's (DPMs) are complex, inter-building systems with close headways, future switching requirements, tight curves, and steep grades.

With only three complex, inter-building systems installed in the last decade, it is difficult to establish a market trend. Besides the two DPMs under construction, complex systems are being considered for half-a-dozen large North American airports, including Los Angeles International, O'Hare, Toronto International, and J.F. Kennedy. It is reasonable to anticipate a market of one large 1000 passenger-place system being installed on an average every four years, or 250 passenger places per year.

After the technical problems of Morgantown, Dallas Fort Worth (Vought), Boeing, Westinghouse and the UTDC ICTS dominate this market. WEDway and Unimobil lack speed, switching, and command-control capabilities.

3.2.3 Recreation

3.2.3.1 Market Description

These markets can be defined as entertainment locations within which a transportation system is required to transfer customers between and/or through the major attraction areas. Markets of this type include:

- Metropolitan/County Zoos: The open-concept- style zoo is now the preferred environment in which to display the animals. This zoo design requires a large acreage of land and normally necessitates the use of some type of transportation to move customers to and through the various animal areas.
- Theme Parks: Many theme parks utilize various types of mobility systems to transfer visitors between attraction areas and may also move the passengers through the areas of interest.

3.2.3.2 Market Characteristics

- A number of locations in this market are now served by several competitors.
- Unhurried and unscheduled customers dominate this market area.
- Walking may/may not be an alternative.
- Comfort and enjoyment are prime requirements.
- The transit system is often the prime means of access to the major attraction points and is therefore considered part of the attraction and "not just a means of transportation".

3.2.3.3 Market Requirements for a Transit System

- Outside operation.

- Vehicle comfort is a prime requirement because of the extended period of time the passengers may be in the vehicles.
- Slim guideways and small vehicles are desired to minimize intrusion upon the theme park environment.
- Normally, elevated guideways are required.
- Very low speeds are required to allow passengers to view the attraction areas.
- High reliability.
- Positive image (futuristic).

3.2.3.4 Market Size and Outlook

Numerous recreational systems have been built in the last two decades. These systems are technologically unsophisticated, with low speeds, simple routing, gentle curves and gradients, and manual operation. Some systems have on-board air conditioning, and most (but not all) have automatic doors.

Approximately 700 passenger places were installed per year in the decade 1967-1977. Since then the market has contracted to perhaps 500 places per year. This can be attributed to saturation in the theme-park market, shrinking capital resources for municipal zoos, and a generally contracting economy. Projects planned or under construction include Dallas Zoo and New Orleans Zoo.

Universal Mobility now dominates this market with approximately 10 systems averaging 500 passenger places. Rohr, an early competitor with several installations, has now dropped out. WEDway systems have been installed only at Disney's own theme parks. Bendix (Toronto Zoo) and Westinghouse (Busch Gardens) are no longer in this market, probably because their products are inherently more costly and complex than the Unimobil competition.

3.3 Competitive Systems

3.3.1 Background

In this evaluation of competitive products in the low-capacity people mover markets, only those that are presently being marketed are considered.

Information has been developed from the following sources:

- Lea Transit Compendium.

- U.S. Department of Transportation reports that describe and assess various people mover systems.
- Direct communication with users and manufacturers of people mover systems.
- Information derived from magazine articles and manufacturer brochures.
- UTDC files.

The Lea Transit Compendium provides the most detailed description of transit systems that are competitive with CAB. Various U.S. Department of Transportation reports and direct communication with manufacturers and users of the various systems have provided valuable information regarding capital, operating and, maintenance costs.

3.3.2 Competitive System Analysis

Systems competitive with CAB are of three general types:

- Moving Walkway Systems
- Bus Systems
- Automated Guideway Transit (AGT) Systems

The following sub-sections provide:

- A system description and summary of existing products where applicable
- System costs
- System limitations
- CAB benefits and disadvantages versus the competitive system

3.3.2.1 Moving Walkway Systems

- System Description:

The system is a continuous conveyor that transports standing passengers over point-to- point distances. Most systems installed are constant-speed systems that normally do not exceed 200 m in length and operate at a speed of 3 km/h. Several companies have attempted to market accelerated-speed walkways which may extend to 900 m in length and operate up to 20 km/h. Very few accelerated systems have actually been installed. These systems can be utilized in the intra-facility market and also in the

inter-facility market if a tunnel or ground-level structure is erected to protect the system from the weather.

o System cost:

- Constant-Speed Walkways: approximately $8000/m (not including tunnel or other protective structure costs)

- Accelerated-Speed Walkways: $8,000-$12,000/m (not including tunnel or other protective structure costs)

o System Limitations:

- Requires major structural provision at time of building construction, including machinery pits below floor level. Retrofitting is usually very difficult.

- Creates absolute barrier to pedestrian cross-movement.

- Intermediate stopping points can be provided only by breaking the walkway into separate sections. Passengers must walk between sections.

o CAB v. Moving Walkway System

Benefits:

- Significantly lower capital cost.

- Significantly lighter guideway requirements that are easy to install within existing structures.

- System flexibility will permit curving and access across the system.

- Significantly greater service capabilities:

  i) Speed - maximum speed of 25 km/h will reduce travel time in many locations.

  ii) Distance - capable of serving points separated by distances approximating 4 km.

  iii) Comfort - offers a smooth, seated ride with the capability to load on a stationary vehicle.

Disadvantages:

- Moving walkways provide continuous service which eliminates waiting time except under extreme conditions.

3.3.2.2 Bus Systems

o System Description:

Non-guideway rubber-tire roadway vehicles that move passengers between stations within a multi-terminal location.

o System Cost:

Buses do not require exclusive guideways and therefore guideway (roadway) costs are not considered part of bus system capital costs.

The approximate vehicle cost for a standard forty-foot bus is $135,000. The passenger demand, route length and trip time determine the number of buses required at a specific location. To compare the cost of this type of system to moving walkway systems, the U.S. Department of Transportation completed a theoretical analysis (Report UMTA-IT-06-0126- 78-4) that estimated a bus system cost of $3,540 per metre, excluding road construction costs.

o System Limitations:

- Vehicle operator requirements generate high operating costs.
- High maintenance costs.
- Air pollution from diesel motors.
- At low volumes, wait times are quite long.
- At high volumes, bus congestion on roads can become a problem.

o CAB v. Bus System

Benefits:

- Significantly lower operating and maintenance costs.
- Exclusive right of way does not impede other transportation vehicles.
- Significantly greater service capabilities:
  i) Speed - travel time will be faster; largely reduced loading/unloading times.
  ii) Comfort - offers a smooth ride in pollution-free vehicles.

Disadvantages:

- Higher capital costs.

3.3.2.3 Automated Guideway Systems (AGT)

These systems contain vehicles that operate singly and in small trains over an exclusive guideway under automatic control.

The following is a summary analysis of AGT systems that are presently being marketed for low-capacity site applications. Cost data for specific site locations are illustrated in Section 3.4.

Westinghouse System

o System Description:

An exclusive guideway system in which rotary motor vehicles receive power from the guideway.

The vehicle capacity approximates 100 standing passengers (few seats are provided in existing vehicles) and cruise velocity is about 40 km/h. The system design is complex, allowing it to meet the basic operating requirements of a downtown people mover system; however, most existing installations in the low-capacity market are fairly simple and have not fully utilized the sophisticated operating capabilities of the system. This product is competitive in the inter-building market and is well suited for complex inter-building route requirements.

o System Limitations:

- Rubber-tired traction requires guideway heating in extreme climates.

- Rotary motors and gearboxes increase vehicle weight and require maintenance.

ICTS System

o System Description:

An exclusive guideway system in which vehicles powered by linear induction motors receive power from the guideway.

The vehicle capacity approximates 85 seated passengers and cruise velocity approximates 75 km/h. The system design is complex as it has been designed to meet the operating requirements of a downtown people mover system. The train control system, which allows short headways under one minute, and speed and tight curving

capabilities, create a system that would not be effectively utilized in many low-speed, short- distance, low-volume applications. It is, however, well suited for complex inter-building routes that connect several major points.

o System Limitations:

- ICTS is overdesigned for most low-volume market application requirements.

WEDway System

o System Description:

An exclusive guideway system in which in-track LIMs propel passive vehicles along the guideway. The vehicle capacity varies between 4 and 18 passengers depending upon vehicle capacity and seating requirements. The vehicles contain a chassis assembly consisting of 12 urethane-covered aluminum wheels and operate at 15 to 25 km/h. This system has been installed in both inter-building and recreational market locations and could also be applied in the intra-building market.

o System Limitations:

- Existing system has no on-board power for air conditioning or heating.

VSL Corporation

o System Description:

An automated cable-driven system designed for short-distance installations. Propulsion of vehicles is accomplished by a traction rope system powered by a drive mechanism in the main terminal. Each vehicle is permanently attached to the cable and may accommodate up to 180 passengers. The system has been installed in inter-building market locations and could also be applied to the intra-building market.

o System Limitations:

- Lack of switching ability limits system to simple shuttle operations, and consequently low volume and long wait times for long systems result.

Universal Mobility System

o System Description:

A monorail transportation system designed for fully automotive operation on a guideway loop with off- or on-line stations. Small

rotary motor-powered vehicles, seating 6 passengers per vehicle, form train sets that operate at speeds of approximately 7-10 km/h. The system has been developed for the recreation market.

o System Limitations:

- No major limitations for this market.
- Rotary motors require maintenance.
- Would not meet other market area operating requirements.

3.4.3 Other Competitive Systems

There are two known guideway systems developed outside North America that appear to be competitive with CAB.

The H-Bahn System, developed by Siemens-DuWag, consists of an overhead guideway with vehicles suspended underneath. The bogies of the vehicles operate inside a boxbeam-type rail and therefore the vehicle track is protected. The system is currently in operation in Dortmund, Germany. Table 2 illustrates major characteristics of the system.

The POMA 2000, being developed by POMA, utilizes small cars mounted on rubber-tire wheels that run on special track with a vertical guiderail and are hauled by a cable. At station entrances, the cars are detached from the cable and slowed by wheels or an auxiliary cable. After passengers board, the doors close automatically and the cars are accelerated by a second set of wheels or auxiliary cable. Major characteristics of this system are also shown in Table 2.

o CAB v. Automated Systems

Benefits:

- Intra-Building Market

  i) The CAB lightweight infrastructure allows installation in this market-place. WEDway is the only other AGT system that may be utilized in this market.

  ii) CAB capital costs are lower than WEDway costs.

- Inter-Building Market

  i) CAB operating capabilities are greater than other simplified technology systems, thereby offering improved service and the opportunity to handle higher volume levels. CAB offers higher speeds, shorter headways, and lower maintenance costs compared to Universal Mobility.

TABLE 2
OTHER GUIDEWAY SYSTEMS

SYSTEM	VEHICLE PERFORMANCE			VEHICLE DESCRIPTION			SYSTEM PERFORMANCE					
	Speed	Capacity	Grade	Propulsion	Services Brakes	Suspension	Capacity	Headway	Network	Switching	Type of Service	Stations
H-Bahn	28km/h	20-65	7%-15%	various options	dynamic through motors	2 steel wheels	3800-10800 pphpd	16-46 s	linear, loop or grid	on-board electromagnetic through one of synchronous linear electric motors	scheduled or on-demand service	On and Off line
POMA 2000	35km/h	20-30	10%-15%	electric motors at stations		rubber tire wheels & pneumatic suspension	7200 pphpd	10-14 s	linear or loop		scheduled	On or Off line

TABLE 3
SYSTEM APPLICATION

SYSTEM - LOCATION	SITE DESCRIPTION	SYSTEM CONFIGURATION	GUIDEWAY ELEVATION	GUIDEWAY LANE LENGTH METRES	NO. OF STATIONS	NO. OF VEHICLES	VEHICLE CAPACITY	PASSENGER PLACES(1)	PERIOD OF OPERATION	PASSENGER VOLUME 1981 '000
Westinghouse										
Atlanta	Airport	Dual-lane shuttle with bypass	underground	3690	10	17	80	1360	21 hrs/day	26650
Busch Gardens	Recreation Ctr.	Single-lane loop	elevated/at-grade	2141	2	2	96	192	11 hrs/day (Mar.-Oct.)	1390
Miami	Airport	Dual-lane shuttle	elevated	820	2	6	99	594	24 hrs/day	4720
Orlando	Airport	2 dual-lane shuttles	elevated	2380	8	8	100	800	24 hrs/day	1800
Seattle-Tacoma	Airport	2 single-lane shuttles	underground	2750	8	12	102	1224	20-24 hrs/day	10720
Tampa	Airport	4 dual-lane shuttles	elevated	2170	8	8	100	800	18 hrs/day	17220
MEDway Trans Systems Inc.										
Orlando	Recreation Ctr.	Single-lane loop	elevated	1401	1	150	4	600	13 hrs/day	4890
Houston	Airport		underground	2380	9	18	12	216	24 hrs/day	2250
Universal Mobility										
Minnesota Zoo	Recreation Ctr.		elevated/at-grade	3190	1	18	16	288	10 hrs/day	290
King's Dominion	Recreation Ctr.		elevated/at-grade	3317	1	54	10	540	11 hrs/day (Apr.-Oct.)	770
Otis/TTD										
Duke University	Medical Centre	2 single-lane shuttles with 2 cars operating in 1 lane	elevated/at-grade /underground	901	3	4	22	88	24 hrs/day	970
VSL										
Las Vegas	Recreation Ctr.	Dual-lane shuttle	elevated	460	2	2	50	100		
Memphis	Civic Centre			550	2	2	180	360		

(1) Passenger Places = Number of Vehicles X Vehicle Capacity

INFORMATION SOURCE: UMTA Reports 06-0126-82-3 and 06-0135-77-5

TABLE 4
SYSTEM CAPITAL COST SUMMARY

SYSTEM - LOCATION	GUIDEWAY COSTS			VEHICLE COSTS			COMMAND AND CONTROL COSTS					
	Total Cost '000	Equiv. Elevated-Lane km	Cost/km '000	Total Cost '000	No. of Vehicles	Cost per Vehicle	Total Cost '000	Total Lane km	Cost/km	Costs for Guide-ways, Vehicle & C&C Equipment per Equiv. Elevated-Lane km - '000	Other Costs '000	Total System Costs '000
Westinghouse												
Atlanta	$22,315	11.06	$2,018	$15,057	17	$885,700	$5,547	2.29	$2,422	$3,881	$31,157	$74,076
Busch Gardens	2,739	1.35	2,029	1,385	2	692,500	853	1.33	641	3,687	2,661	7,638
Miami	3,917	.82	4,777	1,836	6	306,000	1,331	.51	2,610	8,639	8,910	15,994
Orlando	6,136	2.38	2,578	6,109	8	763,625	6,803	1.48	4,597	8,003	11,698	30,746
Seattle-Tacoma	19,754	8.26	2,392	8,324	12	693,700	3,419	1.71	1,999	4,003	25,048	56,545
Tampa	5,496	2.17	2,533	4,540	8	567,500	2,320	1.35	1,719	8,020	11,140	23,496
WEDway Trans System Inc.												
Orlando	4,725	1.4	3,375	2,053	150	13,687	5,026	.87	5,777	8,431	7,085	18,889
Houston	9,288	7.13	1,303	1,368	18	76,000	2,880	1.48	1,946	3,554	12,177	25,713
Universal Mobility												
Minnesota Zoo	3,499	2.06	1,699	3,765	18	175,800	469	1.35	345	3,963	3,214	10,347
King's Dominion	1,720	1.42	1,211	3,784	54	70,100	59	2.06	29	3,918	3,600	9,163
Otis/TTD												
Duke University		.98			4			.90				6,154
VSL												
Memphis		.55						.55				5,108

TOTAL COSTS: The systems were constructed over a period of several years. For the purpose of comparative analysis, to update capital costs the wholesale price index is used to adjust all hardware costs to 1st quarter 1983 cost levels.

VSL is restricted to shuttle operation, which reduces volume-level capabilities. CAB is price competitive with both systems.

ii) Most site locations in the low-speed, low-capacity market require basically simple operating requirements. CAB has the capability to meet simplified operating requirements and capital costs are significantly below those of other more complex technology systems such as Westinghouse and ICTS.

iii) CAB capital costs are lower than WEDway costs and operating capabilities are similar.

- Recreation Market

i) CAB can compete favourably on a capital cost basis with WEDway and Universal Mobility.

Disadvantages:

- Inter-Building Market

i) CAB technology has not been developed to incorporate switching, tight curves, and steep grades.

3.4 Capital Cost Data For Automated Guideway Systems

Table 3 describes various systems installed at specific site locations. Table 4 illustrates capital costs as shown in the UMTA Report 06-126-82-3 for the Westinghouse and Universal Mobility systems and also the WED Transportation system at Houston. Costs for the WED system at Disneyland appear overstated in this report and consequently the costs as shown in report 06-0135-77-S have been utilized. Otis and VSL cost figures are based on information provided by representatives of these firms. All costs have been updated to 1983 dollars using the Producers' Price Index (PPI) for machinery and motive products.

The following are definitions of costs as stated in the 1982 UMTA report:

- Guideway - The vehicle roadway including site preparation, foundations, supporting structures, pedestrian walkways, running and guidance surfaces, wayside switching equipment, and special facilities for melting snow and ice, if required.

- Vehicles - The rolling stock.

- Command and Control - Wayside and central control and communications equipment including operational software and voice and video communication systems.

- Other - This includes:

  - Maintenance and Support - Maintenance and storage facilities including special vehicles and equipment.

  - Power and Utilities - Electric power transformers, feeders, switchgear, wayside power rails, and normal housekeeping power equipment.

  - Stations - Passenger loading platforms, shelters, access facilities such as ramps, stairways, escalators, elevators, graphics, fare-collection equipment, co-ordinated doors and other facilities related to the movement of passengers into and out of vehicles.

  - Engineering and Project Management - Architectural and engineering services, system design and integration, acceptance testing, and over-all project management.

In evaluating the capital cost data, it must be recognized that costs for similar systems may fluctuate significantly because of various factors that include:

- Economies of scale inherent in larger systems;

- Environment: the site location and environment may create a significant difference in the work tasks and labour costs to construct the system;

- Technology level required: the system operating requirements and design requirements (e.g., an airport system requiring almost 100% availability, 24 hours per day, 365 days per year, or a recreation centre requiring only 80% availability, 12 hours per day, 140 days per year) will have a significant impact on total system costs;

- Bid competitiveness; and

- Regulations.

Table 5 summarizes capital costs on a per metre and per passenger place basis. The costs of the Westinghouse (Miami) and UTDC (Detroit) Downtown People Mover Systems are also illustrated to reflect the cost levels of these technologies. Application costs within each market (recreation and inter-building) have varied significantly. However, recreation system costs approximate $5,000-$7,000 per metre. With respect to inter-building airport applications, costs approximate $10,000-$20,000 per metre, and with respect to DPM systems upwards of $23,000 per metre. WEDway, with their recent application at Houston airport, appear price competitive as well as service competitive with Westinghouse in the airport system market.

TABLE 5
SYSTEM CAPITAL COST ANALYSIS

SYSTEMS	TOTAL SYSTEM COST PER METRE	COST PER PASSENGER PLACE PER METRE	SYSTEM COST PER METRE EXCLUDING GUIDEWAY COSTS	COST PER PASSENGER PLACE PER METRE EXCL. GUIDEWAY COSTS
Westinghouse				
Miami City	$ 38,800	$ 38.03	$ 31,900	$ 31.27
Atlanta Airport	20,100	14.77	14,000	10.31
Busch Gardens	3,600	18.59	2,300	11.92
Miami Airport	19,500	32.80	14,700	24.79
Orlando Airport	12,900	16.11	10,300	12.93
Seattle-Tacoma Airport	20,600	16.80	13,400	10.93
Tampa Airport	10,800	13.53	8,300	10.37
UTDC				
Detroit	23,100	20.88	18,100	16.38
WEDway Transporting System Inc.				
Orlando	13,500	22.48	10,100	16.85
Houston	11,800	50.00	6,900	31.95
Universal Mobility				
Minnesota Zoo	4,700	16.00	1,900	10.86
King's Dominion	2,800	6.89	1,400	5.96
Otis/TTD				
Duke University	6,830	77.62	(1)	(1)
VSL				
Memphis	6,900	19.27	6,900 (2)	19.27
Las Vegas	6,600	66.30	4,500	45.00

(1) Guideway cost data unavailable.
(2) Guideway consists of an existing bridge foundation and therefore guideway costs are low.

3.5 Operation and Maintenance Cost Data

Table 6 illustrates the O&M costs incurred in 1983 dollars for the operation of several systems. The data have been developed from the UMTA report previously noted. These data are compared with projected CAB cost data in a separate document.

The following are definitions of costs as stated in the report:

- Labour - Costs associated with the personnel for system administration and engineering, operation, and maintenance.
- Utilities - Costs of electricity, natural gas, etc.
- Materials and Services - Any "pro rata" share of the general management costs as well as other overhead costs.

In comparing the O&M costs for AGT systems, the Consumer Price Index (CPI) for urban wage earners and clerical workers in the United States was utilized to adjust the costs to January 1983 dollars.

In evaluating the O&M data, several factors affect the level of costs shown. These include:

- Power Costs - These costs vary depending upon the location and quantity of power consumed.
- Area Labour Costs.
- Guideway Heating - Some locations require heated guideways which increase operating costs.
- Cost System - A labour force dedicated to a system creates higher costs than a labour force that is spread over an entire facility.
- Warranty - New systems still under warranty show reduced O&M costs.

The lack of labour costs for Houston and Miami and the low figure for Tampa are reflected in correspondingly high materials and service costs. This is the result of service contract agreements.

3.6 Specific Site Location Operating Requirements

Two specific sites that are considered to be potential markets for the CAB system are Toronto International Airport and Expo'86.

3.6.1 Toronto International Airport

A major problem at the airport is that the Terminal 1 parking garage is often filled to capacity and land is unavailable to provide further parking space in the immediate vicinity of the terminal. To

	LABOUR COSTS			UTILITY COSTS		MATERIALS & SERVICES		G&A		SYSTEM O&M COSTS/ OPERATING HR.		SYSTEM O&M COSTS/ VEHICLE - KM		SYSTEM O&M COSTS/ PASSENGER CARRIED	
	Total Costs '000	Operating Hours	Cost/ Operating Hour	Total Cost '000	Cost/ Operating Hour	Total Cost '000	Cost/ Operating Hour	Total Cost '000	Cost/ Operating Hour	Total Cost '000	Cost/ Operating Hour	Vehicle Kilometres	Cost/Vehicle Kilometre (Dollars)	Passengers Carried '000	Cost per Passenger (Cents)
Westinghouse															
Atlanta	$2,624	7,765	$ 339	$123.9	16	$251.0	$ 32	$268.0	35	$3266.9	$421	1,236,360	$ 2.64	26,652	12.3
Busch Gardens	120	1,565	77	10.8	7	60.0	38	--	--	190.8	122	37,387	5.10	1,342	14.2
Miami	--	8,760	--	65.1	7	277.0	32	--	--	342.1	39	374,652	.91	4,725	7.2
Orlando	329	2,472	133	40.4	66	15.2	6	3.2	1	387.8	157	295,757	1.31	1,804	21.5
Seattle-Tacoma	683	8,030	85	23.3	3	155.0	19	--	--	861.3	107	924,824	.93	10,722	8.0
Tampa	33	5,305	6	96.2	18	681.0	126	17.7	3	827.9	154	572,994	1.44	17,223	4.8
McDaney Trans Systems Inc.															
Orlando	292	4,114	71	74.0	18	54.2	13	33.5	8	453.7	110	930,413	.49	4,885	9.3
Houston	--	2,688	--	9.5	4	355.0	132	--	--	364.5	136	122,122	2.98	2,500	14.6
Universal Mobility															
Minnesota Zoo	219	2,720	81	32.9	12	16.6	6	--	--	268.5	99	10,517	25.53	288	9.3
King's Dominion	32	1,364	23	42.0	31	8.7	6	--	--	82.7	61	81,414	1.02	770	10.7
OTIS/TID															
Duke University	416	8,760	47	14.7	2	65.0	7	--	--	495.7	57	111,433	4.45	968	51.2

TABLE 6
SYSTEM OPERATING AND MAINTENANCE COST STATISTICS

alleviate this situation, consideration is being given to the construction of a parking facility north of the Administration Building. A people mover system would then be required to connect Terminals 1 and 2 and provide access to the new parking facility.

When UTDC developed a proposal to utilize an ICTS system to link Terminals 1 and 2 and a planned Terminal 3, the information needed to establish a transit system operating requirement was developed. This information has been utilized in developing the following compliant air-bearing system operating requirements. It is important to note that this study has not considered which system is best suited to meet the long-term requirements of the airport. The purpose is only to determine whether the CAB system has the capability to meet the operating requirements of the location.

- Capacity: The TIA Intra-Airport Transportation Study (Technical Working Paper No.116) identifies various demand scenarios for the movement of employees and passengers between the Terminals, a ground transit terminal, and remote parking garage locations. The 1991 peak hour demand projection has been used. If it is assumed that a parking garage is located north of the Administration Building and that Terminal 3 and a ground transit terminal are not constructed, following in Table 7 are passenger demand levels for the system:

  Table 7: System Capacity Requirements

Line	Demand pphpd
Terminal 1 to Remote Parking Garage	1893
Remote Parking Garage to Terminal 2	213
Terminal 2 to Remote Parking Garage	560
Remote Parking Garage to Terminal 1	2660

  If a ground transit terminal were constructed near the remote parking garage, the peak capacity on the most heavily used line would increase to approximately 3,000 pphpd.

- Speed: Airport transfer systems are required to provide fast service between parking garage and terminal locations. The total travel time should not exceed 5 minutes and therefore the system should have the capability to attain a velocity of 25 km/h.

- Ride Comfort Requirement: As the total travel time is brief, seating need not be provided.

- Service Level Expectations: High reliability and availability levels are required.

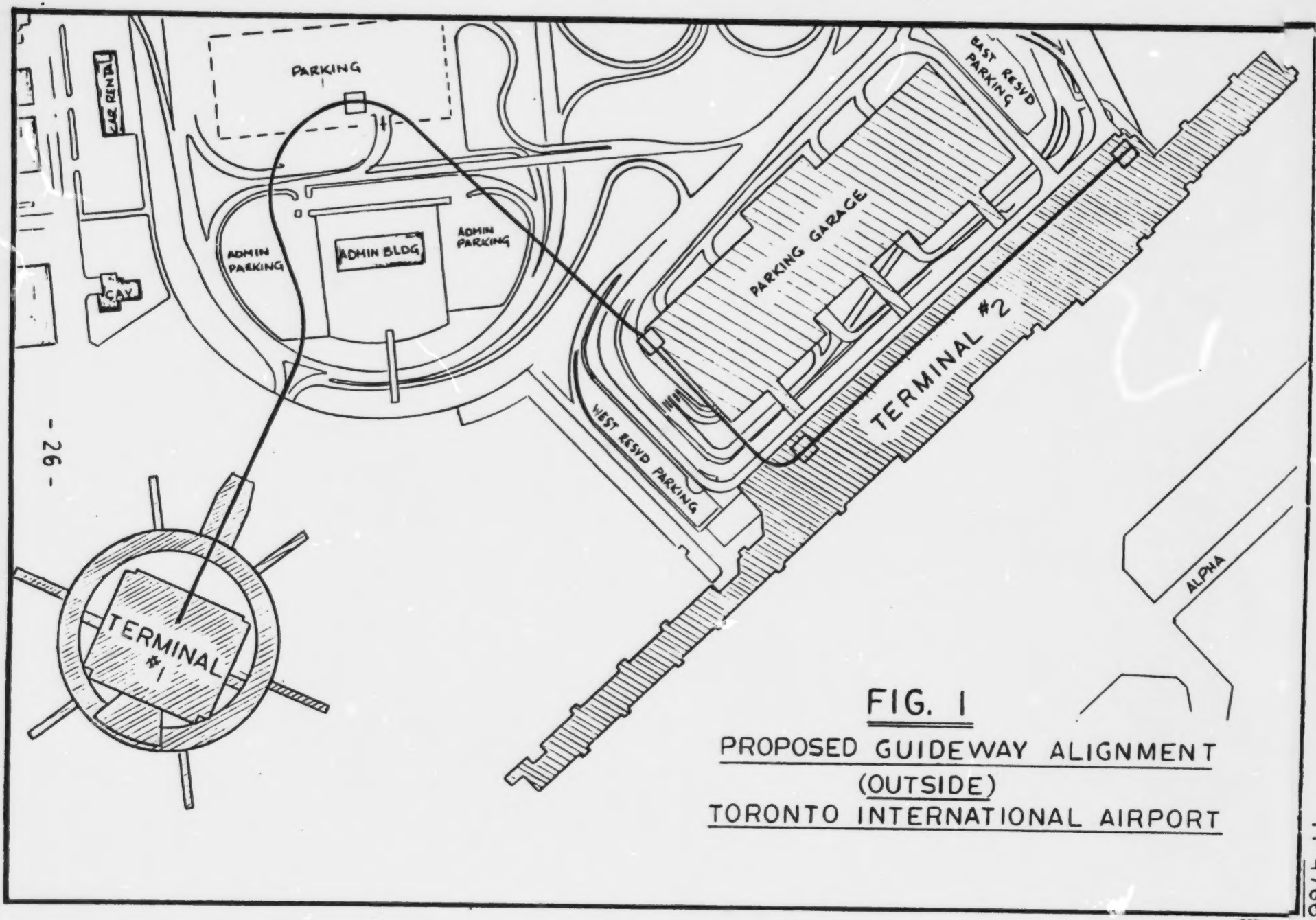


FIG. 1

PROPOSED GUIDEWAY ALIGNMENT

(OUTSIDE)

TORONTO INTERNATIONAL AIRPORT

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- Noise Level: It should be consistent with or superior to normal transit standards. The maximum noise level would not exceed 65 dba.

- Safety Requirements: Command and control equipment must prevent vehicle collisions. Vehicle interior design and materials will minimize fire and other hazards consistent with standard transit regulations. Emergency procedures are required to remove passengers from stranded vehicles.

- Maintenance Requirements: An enclosed facility is required to perform preventive and repair vehicle maintenance. The system would include switching capability to allow vehicles to be routed to the maintenance area.

- Human Factors: The vehicles would provide excellent visibility of adjacent surroundings and allow rapid entry and exit of passengers carrying baggage and packages.

A second potential area of application at the airport for a people mover system is at Terminal 2. To offer an improved level of service for travelling between terminals, a system is required either in combination with the moving walkway system or to replace the moving walkway. It would run the length of Terminal 2 and connect through the tunnel with Terminal 1. This system would necessitate several operating requirements which would be different from the application previously considered. These are:

- Guideway Alignment: A potential guideway alignment is illustrated in Figure 2. The length of the guideway within Terminal 2 would approximate 800 metres. If this system were to replace the existing moving walkway an additional 250 metres of guideway would be required. In this situation, the total system would consist of two separate independent sections connected by an escalator. Both sections would be linear and contain no curves. The guideway within the Terminal would be at-grade and would require periodic pedestrian guideway crossing areas. The guideway would be enclosed and therefore protected from the weather. Stations would be required at approximately 75-metre intervals within the Terminal area.

- Capacity: The estimated peak capacity would approximate 1000 pphpd.

- Speed: The system must provide a travel time that is less than walking time; a maximum velocity of 10 km/h would provide this type of service.

- Safety Requirements: The command and control system, besides preventing vehicle collisions, must also stop vehicles when pedestrians are crossing the tracks at crosswalks.

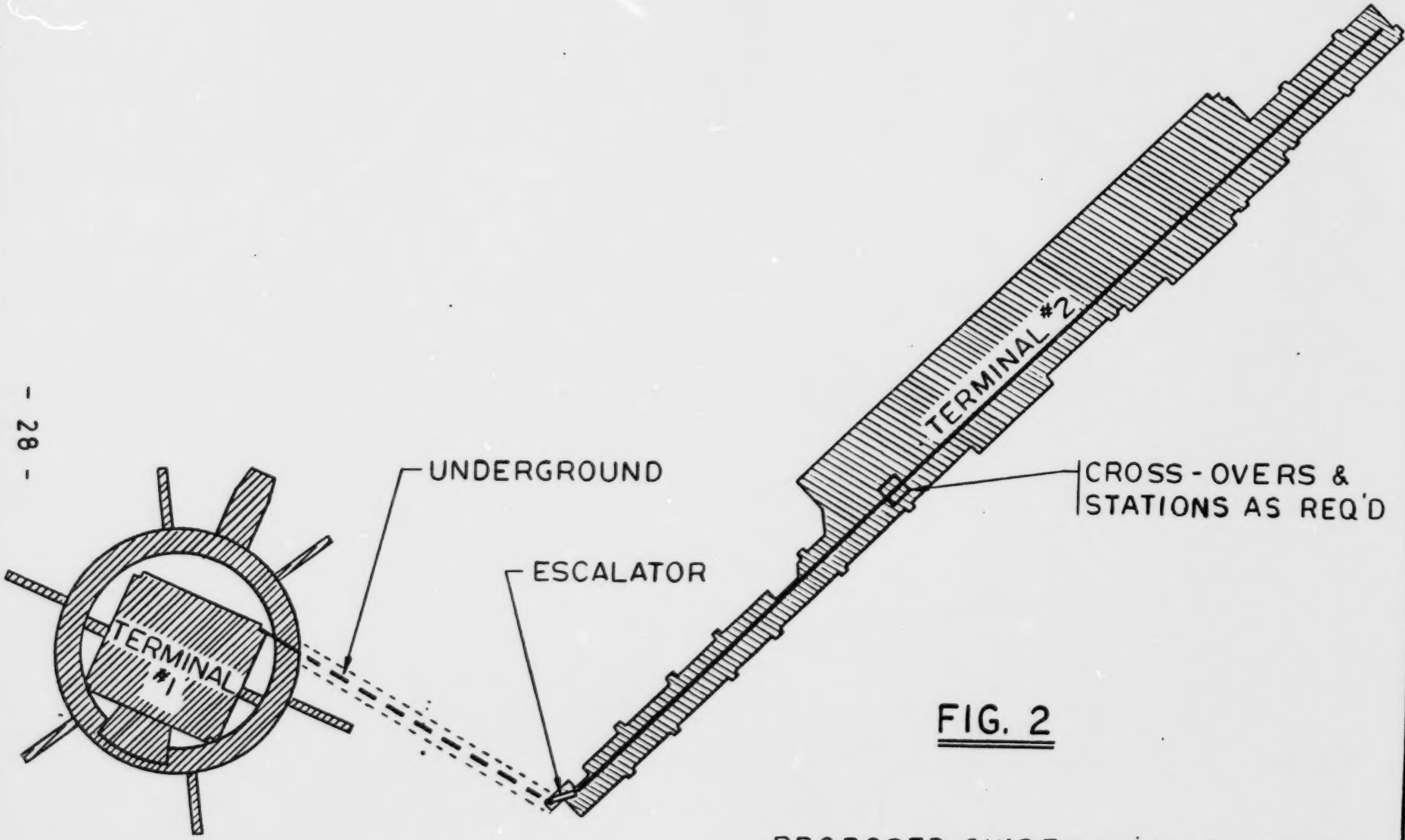


FIG. 2

PROPOSED GUIDEWAY ALIGNMENT
TORONTO INTERNATIONAL AIRPORT

3.6.2 Expo'86

The Expo'86 land site is long and narrow, extending along the Burrard Inlet waterfront. Transportation access to the site is excellent; however, a people mover system within the site area is required to transfer visitors between the various exhibits and entrance/exit gateways. Senior officials of Expo'86 have indicated a strong interest in utilizing the compliant air-bearing system as the major system for distributing people throughout the site area. The following are key operating requirements as developed through preliminary discussions with the site planners and architects:

- Guideway Alignment: A proposed route is illustrated in Figure 3. The route is a loop configuration totalling approximately two kilometres. The greatest degree of curvature in the route layout would not exceed a 40-metre radius. An at-grade guideway is required to facilitate access to the system and pedestrian track crossings would be required at regular intervals. The system would operate outside and therefore be exposed to weather conditions.

- Modal Interfaces: Expo'86 visitors will reach the site periphery through road access, the ALRT system and the water-ferry systems. However, all these systems have their end stations located off the Expo site and visitors will be required to walk through the entrance gates to gain access to the proposed compliant air-bearing system.

- Capacity: The projected volume for the 5½-month exposition is 13 million visitors, which creates an average attendance of approximately 80,000 per day. Based on these very general figures, the preliminary estimate of the required system capacity is 5,000 pphpd.

- Speed: The system will be available as an alternative to walking and will consist of many boarding/deboarding points along the route. Therefore a low-speed system with a maximum velocity of 10 k/h is acceptable.

- Ride Comfort Requirements: The system must be designed to provide maximum comfort to weary Expo visitors. Therefore, full seating is required.

- Service Level Expectations: The exposition objective is to demonstrate effective new transportation technology and therefore high reliability and availability are required.

- Noise Level: It should be consistent with or superior to normal transit standards. The maximum noise level should not exceed 65 dba.

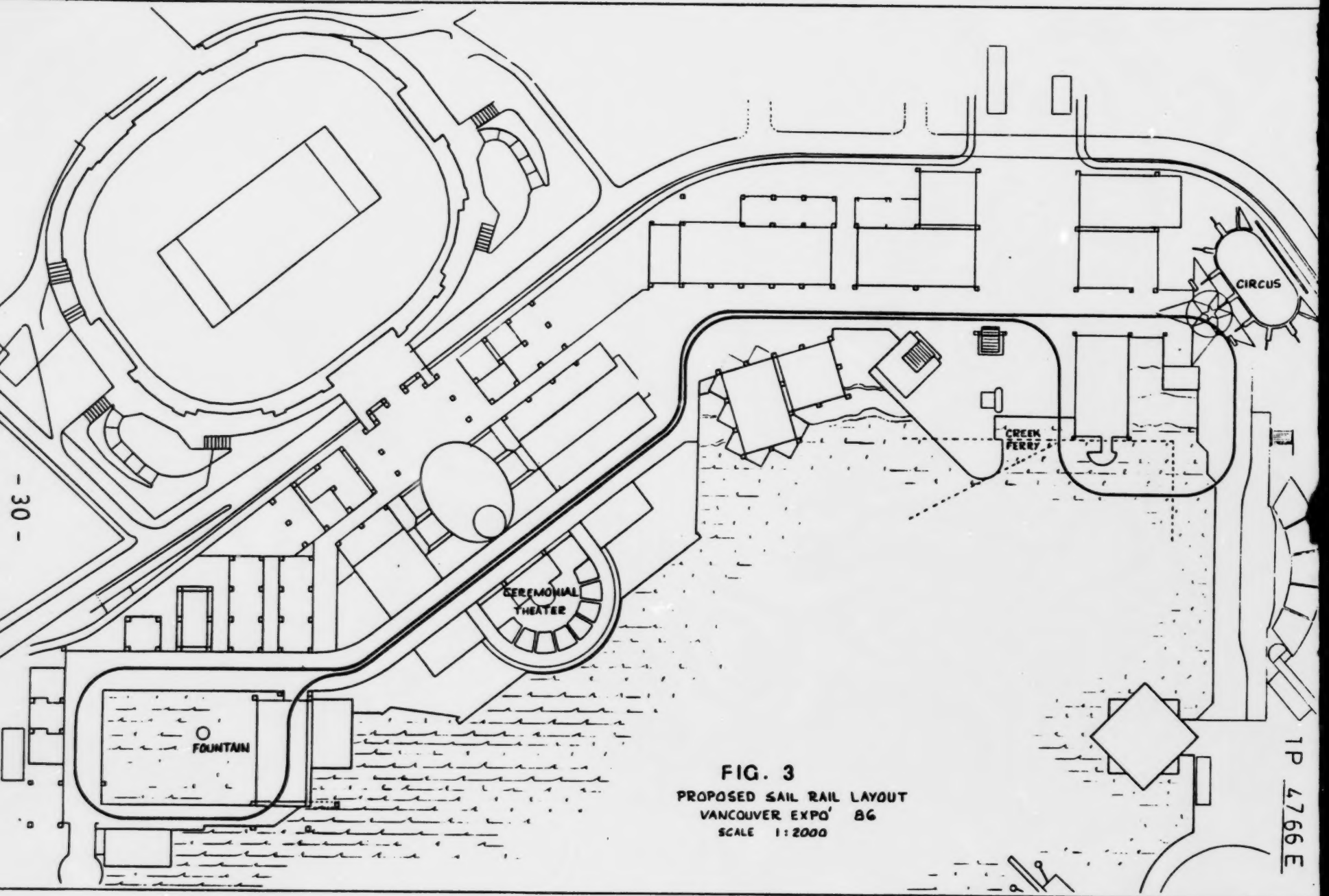


FIG. 3
PROPOSED SAIL RAIL LAYOUT
VANCOUVER EXPO' 86
SCALE 1:2000

TP 4766E

- Safety Requirements: Command and Control equipment must prevent vehicle collisions and ensure that vehicles stop when visitors are crossing the tracks at pedestrian crosswalks. Vehicle interior design and materials will minimize fire and other hazards consistent with standard transit regulations.

- Maintenance Requirements: An enclosed facility is required to perform preventive and repair vehicle maintenance. The system should include switching capability to allow vehicles to be routed to the maintenance area.

- Human Factors: The vehicle should provide excellent visibility of adjacent surroundings and facilitate entry and exit of passengers including small children and the elderly.

4.0 SYSTEMS CONFIGURATION - THE PRODUCT

4.1 Purpose

The purpose of the engineering study, is to determine preliminary system configurations for a powered compliant air-bearing system and develop a general operating scenario of the system including order of magnitude cost estimates.

4.2 Description of Technology

A transportation device system for moving goods or people must provide for three technical requirements, independent of any other design considerations:

Propulsion: The first requirement is to move the vehicle, in acceleration braking, or steady state. For ground vehicles this is normally provided by internal combustion or electric traction motors driving through wheels and relying on adhesion. Other methods include attaching, via friction, to a powered wire rope, cogs, or, as in the ICTS, an on-board linear motor. The last method does not rely on adhesion.

Levitation: The second requirement is to keep the vehicle above the surface. Most vehicles rely on wheels rolling on a surface to provide levitation, e.g.: pneumatic tires on concrete. The penalty associated with levitation is drag or retarding force. Normally this is a combination of bearing friction and a coefficient of rolling friction.

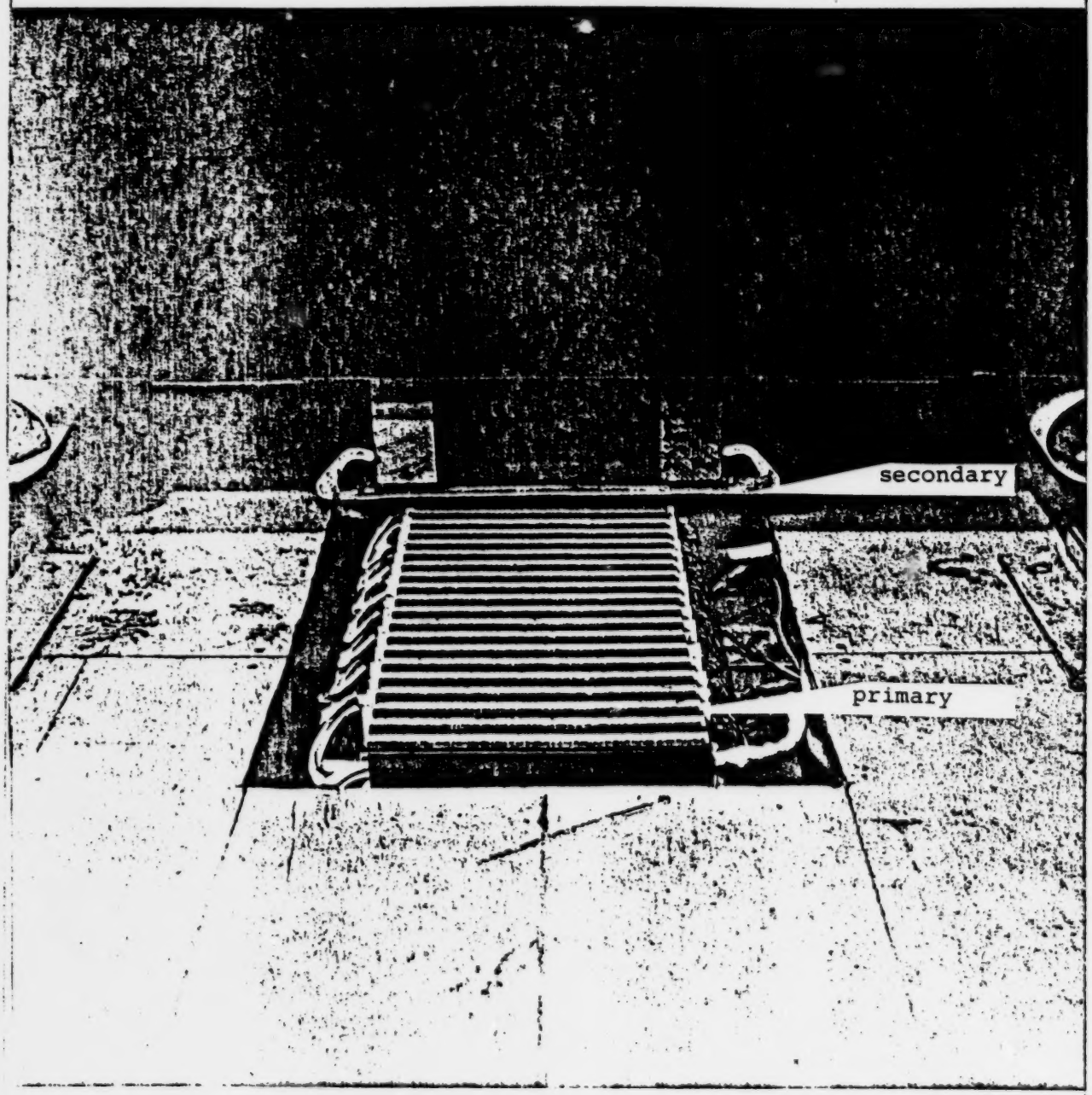
Guidance: The third requirement is to constrain the vehicle to follow a particular path. For railed vehicles this is accomplished by providing both track and wheel with a small angle relative to the horizontal, and flanges on the wheels to physically constrain the vehicle in extreme cases. Where automatic operation is required for pneumatic tires, usually horizontal wheels track a vertically-oriented surface.

The technology examined in this study comprises a blending of two separate technologies:

- Propulsion - Linear Induction Motors
- Levitation and Guidance - Compliant Air Bearing

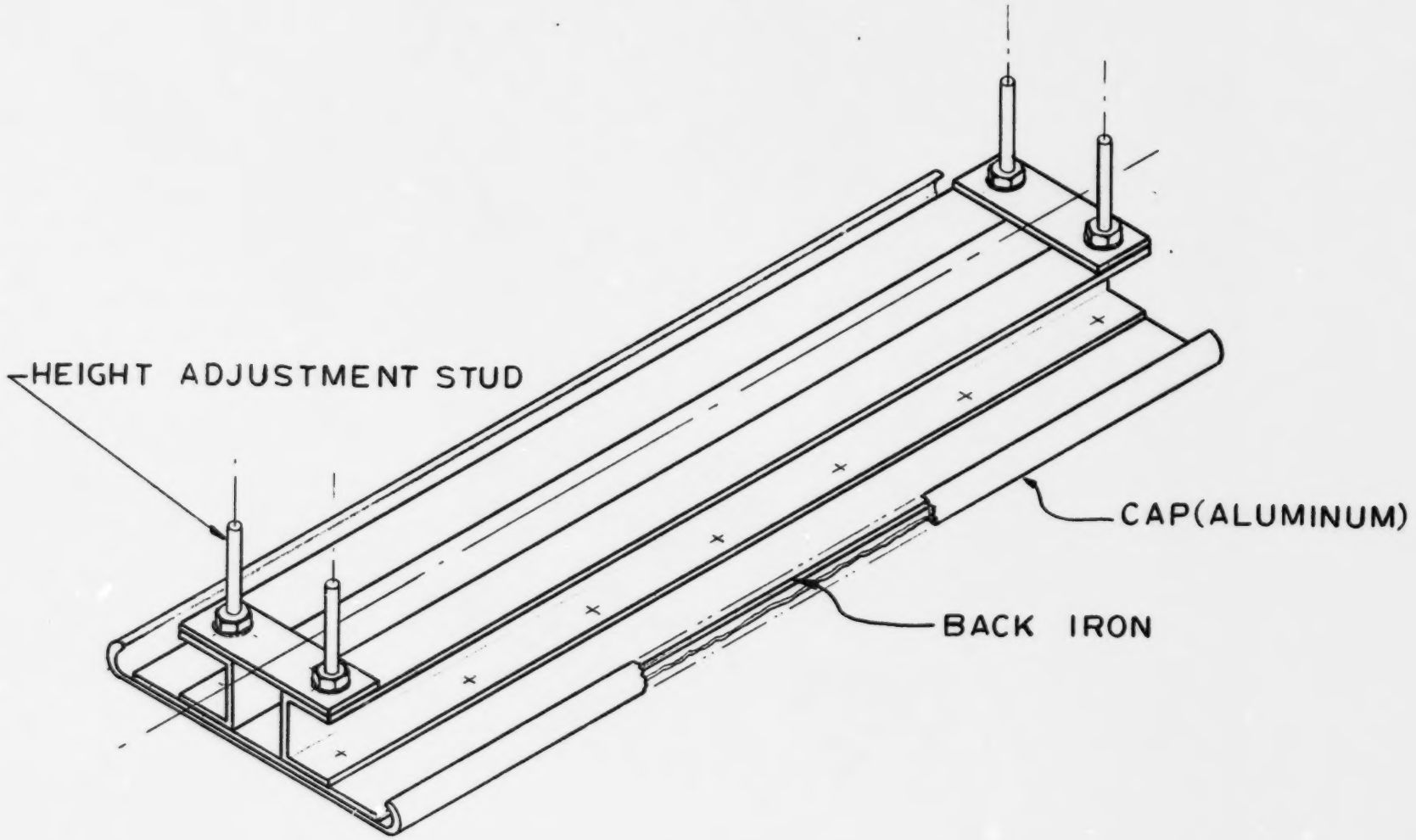
4.2.1 Linear Induction Motors

A linear induction motor comprises two components:



LINEAR INDUCTION MOTOR

FIG. 4



REACTION RAIL SUB-ASSEMBLY

FIG. 5

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(i) The primary winding which consists generally of iron laminations grossly arranged to provide a series of magnetic poles each oriented laterally with respect to the surface. Between the poles are slots containing copper wire windings. The usual configuration is shown in Figure 4.

(ii) The secondary winding usually consists not of a winding but rather of a sheet of aluminum which provides the electrically conductive body. The aluminum is normally backed by a sheet or sheets of iron which improve efficiency by providing a magnetic path for the magnetic fields generated by the primary. The general arrangement of the secondary is shown in Figure 5 and is often termed reaction rail.

When the primary is energized with an AC current in proximity to the secondary, forces are generated, the force of interest is thrust in the plane of the faces and in the direction of the travelling wave. This force is used to propel the vehicle.

In the use envisaged in this study, the LIM primary and its controls are located in the track, with the secondary attached to the underside of the vehicle. When the LIM is activated the vehicle over it experiences propulsive thrust which may be in an accelerating or braking direction.

It is also envisaged that the power supply to the LIM will be standard 60 Hz commercial supply, obviating the need for complex power-conditioning units as found on LIM on-board systems.

The advantages of this approach vis-à-vis LIM on-board or other means of propulsion are:

- Light vehicle carrying minimal propulsion components.
- Reduction in vehicle complexity.
- No moving parts in propulsion components.
- No propulsive power transfer to vehicle.
- The design ability to tailor propulsion components to local requirements (e.g.: grade).
- Provides a system with high inherent reliability and no significant loss of performance or function with failure of an individual unit.
- Ability to use local standard power supplies and reduction in power-conditioning requirements.

4.2.2 Compliant Air Bearing

The technology examined in this study provides both levitation and guidance. It consists basically of a flexible member attached to the vehicle between the vehicle and the track. The member consists of a length of fibrous cellulose material in a sheet wrapped around a cardboard tube (roll of toilet paper). The assembly is crushed to flatten the core then surrounded by a thin polyethylene cover. The rail is an aluminum extrusion approximately 130 mm wide. The upper surface is a segment of an arc with a radius of approximately 150 mm. The centre portion of the track carries air at approximately one to two atmospheres above gauge, released to the curved surface through tiny holes. When the flexible member (shoe) rests on the track a thin air cushion is formed, which largely supports the load applied. By virtue of the curvature in the top surface of the track, guidance is also provided.

The advantages of this technology vis-à-vis conventional forms of levitation are thought to be:

- Low vehicle cost, since the shoe is inexpensive compared with axles, wheels, bearings, etc. In addition, and depending on the extent to which it is a true air cushion device, wear may be extremely low. Thus maintenance costs are potentially small. The shoe also provides inherent vehicle suspension, saving that cost.

- Track cost is low since the rail is a simple aluminum extrusion where normal production tolerances are adequate. The rail is light and easy to lay.

- As a levitation system, it can be characterized as having extremely low unsprung weight which results in low running loads and good ride quality.

- The guidance is excellent in terms of the stability characteristic and resultant ride.

- As a system with light and distributed loads and lack of significant shock loading, it leads to lower impositions on the guideway and vehicle suspension.

- The vehicle weight is reduced.

- Noise arises primarily from the supply of air to the surface; the potential exists to reduce this to below background levels for most environments.

In this study the blending of compliant air-bearing levitation and guidance is mutually enabling and synergistic.

4.3 Review of Technical Questions

In the application of technologies to a transportation concept such as a "people mover," immediate questions arise which centre on technology definition and limits. Once the technology is understood a second set of questions arise. These are concerned with how the technologies may be utilized or modified to meet an operating requirement and perhaps be optimized to some degree. The third set of questions address the "system" which includes all ancillary components and what is required to make it a reliable, safe product.

This study primarily addresses the first two questions. It engages in system design questions only to the extent of assuring that solutions are available and judgementally practical.

4.3.1 Linear Motor Questions

1. Are practical linear motors operating at 60 Hz available and what are their leading characteristics relative to

- o Synchronous speed?
- o Thrust relationship with speed and reaction member?
- o Vertical force relationship with speed and reaction member?
- o Efficiency?
- o Controllability?

2. What design variables are at our disposal to meet the specific system requirements?

On the basis of theory and empirical data it is largely possible to answer these questions.

4.3.2 Compliant Air-Bearing Questions

A similar set of questions arise:

1. What are the leading performance particulars?

- o Drag on straight?
- o Lateral and vertical curvature performance?
- o Maximum and minimum loadings?
- o Vertical deflection characteristics?
- o Allowable speed?

- o No-air drag?
- o Tolerance to misalignment?
- o Air required?
- o Switchability?
- o Outside operation?

2. What design variables are at our disposal to meet the specific system requirements?

- o Shoe length?
- o Air pressure?
- o Air hole number and direction?
- o Shoe diameter?

The theory of operation of the compliant air-bearing technology is not well developed. Nonetheless, based on examination of the experimental work of UTIAS, E.B. Eddy, NRC and UTDC, empirical principles emerge which serve as a foundation for this work.

4.3.3 System Questions

1. How does the LIM spacing/cost tradeoff question interact with:

- o Vehicle drag, curving?
- o Low jerk operation?
- o Vertical force?
- o Suspension characteristic?
- o Method of LIM control?
- o Method of vehicle control between and at stations?
- o System reliability/consistency?
- o Reaction member design?
- o Guideway design?

2. How is the vehicle/train to be controlled safely?

4.4 Operating Scenario

In the course of this study, an attempt was made to examine the application of the technology in the broadest possible transportation context. The range of variables and interactions is so immense as to preclude deriving useful conclusions in the context of a small study.

As an aid to providing direction, a set of market-oriented operational requirements was derived. These are recorded in Section 3 and similarly provided insufficient guidance with respect to concluding feasibility. In order to provide the evolution, it is necessary to focus on a particular system, conceptually design the system, and evaluate the result. To accomplish this, certain technology variables or "building blocks" are postulated and a set is selected. This is shown in Figure 6.

In addition the "key operating requirements" were extracted (Figure 7) and the "commercial" application was selected.

The combination of variables and requirements selected represents:

- An operational system description.
- A simple baseline from which the impact of additional capabilities can be judged.
- At the present state of knowledge, an application which appears achievable.
- An application which fits the general intuitive concept of a quiet, convenient, inexpensive low-speed people mover.

VARIABLE		OPTIONS		SELECTED
Capacity	Low	Intermediate		Low
Route Type	Simple	Complex		Simple
Vehicle	Small	Intermediate		Small
Environment	Inside	Outside		Inside
Headways	Very Short	Short	Long	Long
Right-of-Way Access	No Access	Limited Access	Unrestricted	No Access
Speed	Low	High		Low
Controls	Driver	Automatic		Automatic

FIGURE 6 TECHNOLOGY VARIABLES

KEY OPERATING REQUIREMENTS

ITEM	COMMERCIAL	THEME PARKS	APM*
Capacity	500 - 3000	500 - 4000	3000 - 10,000
Travel Time	Walking	Walking	Max 10 min•
Station Dist.	100 - 300m	1 - 5 km	0.5 - 2 km
Seated/Standing	All Seated	All Seated	Most Standing
Freq. of Service	1 - 2 min	10 - 30 min	2 min
Method of Control	Sequence	Manual	Automatic
Availability	Transit Standards	Transit Stds	Transit Stds
Environment	Protected	All Weather	All Weather
Reliability	Transit Standards	Transit Stds	Transit Stds
Right of Way	Most at Grade	Most Elevated	Mixed

* Airport People Mover

• From Start to Finish

KEY OPERATING REQUIREMENTS
FIGURE 7

4.5 GENERAL SYSTEM DESCRIPTION

4.5.1 System

A typical SailRail transportation system is a single guideway shuttle operating indoors. The length is between 100 and 400 metres with two termini and one intermediate station having a non-access right of way between. An option is a level pedestrian crossing occurring at some point along the track. System overall service provides speeds faster than walking with a peak train speed of 6.5m/s. System capacity is over 200 people per direction per hour or (ppdph).

The passengers are comfortably seated, riding in an open vehicle. Very moderate curvature and grade are accommodated.

In general the system is quiet, convenient and comfortable.

4.5.2 Vehicles

Vehicle design and layout are based on criteria derived from quality service considerations:

- o 100 percent seating
- o high door-to-seat ratio
- o high comfort and space level
- o excellent visibility and openness.

The vehicle is 2.0 metres long by 1.8 metres wide. It is symmetrical with doors on each side; however, a station would normally be on one side only. The top is about 1.1 metres above the track and is open. Six passengers are carried, two rows of three abreast, facing inwards fore and aft. Dimensions permit a generous width allowance per passenger and plenty of legroom, accommodating luggage under the seating.

The vehicle does not contain services; however, a battery is required to provide door operating and safety interlock operation. The normal minimum consist is a train of two cars which are connected with a single mechanical (but isolated) tow bar at the reaction rail level. Expansion is accommodated by adding vehicles in pairs.

4.5.3 Guideway

The guideway is considered to be merely a typical floor or walkway structure. Along the private right of way portion a solid barrier is required which typically consists of a durable fence structure bolted to the floor.

1. Supply - To operate the system, two distinct supplies are required, air for levitation and electricity for propulsion and control.

2. Air - For a non-essential service, a single non-redundant supply of air is adequate. A single air compressor of the low-pressure vane type will be sufficient. They are reliable, quiet in operation, and efficient.

3. Electricity - The system will use standard 3-phase, 60 Hertz power supply to the linear motors and the air compressor. A voltage of 208 is satisfactory, but 600 V are preferable. A single substation is required.

   The propulsion electricity supply system is fully insulated and isolated, providing a completely safe guideway for maintenance operations and potential emergency cases.

4.5.4 Track

The track consists of the following elements which can be, if required, made virtually flush with the adjoining surface:

1. Linear Motors - Generally spaced at 4 m in cruise segments and at 2 m in accelerate or brake segments. Each motor incorporates its own sensors, to detect the presence of trains, and solid state controller. Each unit is approximately 0.4 m by 0.2 m and bolted to the guideway. The unit is perfectly safe insofar as inadvertent human contact is concerned.

2. Track - Two anodized aluminum tracks are spaced at about 1.5 metres. They are about .13 m wide and may be surface mounted or made flush, presenting a concave element with a maximum depression of about 10 mm. Track attachment to the guideway is by small clips on each side, bolted down. The track is in 15-metre sections with mechanical joints. Small gaps do not affect ride quality. The track is generally not shimmed except to maintain correct vertical tolerances at the linear motor units, provided that the guideway is reasonably smooth.

3. Air Supply - For an interior installation the main air supply is via an outer passage in the track. Feed to the air holes is from a centre cavity in the track. Passage of air from the outer cavity to the inner cavity is controlled by a pressure regulator and valve in 15-metre sections, permitting sequenced operation of track segments.

4.5.5 Train Control

Normal

Normal train control is achieved by dividing the station-to-station run into a number of distinct segments each independently controlled and powered.

Station Acceleration

Starting from rest and accelerating to cruise speed is jerk-limited and load compensation is provided in part by inherent vehicle suspension characteristics which modify the LIM air gap. Each linear motor is controlled by its own sensor.

Cruise

Cruise speed is maintained within an acceptable range passively based on the nature of the thrust-speed characteristic of the LIM.

Braking and Position Control

This section brakes the vehicle in a controlled manner as it approaches the station. Entry to the station is at very low speed; final positioning is achieved passively by entering a track section with no air. In the braking section constant brake rate is maintained by the use of a feedback loop controller.

4.5.6 Emergency

Loss of braking is critical at the approach to a station or a level crossing. The system algorithms are such that an emergency such as loss of power, will lead, in a failsafe manner, to loss of air in the track. The resultant brake rate is about $1.5 m/s^2$ independent of weight.

4.5.7 Operation

The operation of the system is automatic (largely sequential) except as overridden by the passenger.

The vehicle will enter the station at a very low speed, provide an audible warning, and stop. The doors will not open except as requested by a passenger using an interior "door open" button, or by a rider using an exterior "door open" request button. In both cases the doors open without assistance.

The doors are interlocked with the station propulsion system so that any door open disables propulsion. The doors will close in a predetermined time overridden only if additional requests are made, or if the door is unable to close because of an obstruction. An audible signal is created and the vehicle proceeds to the next station.

Level crossing is also an option. In the absence of a train, doors will close off the operating guideway. The region will be defined by a pressure-sensitive surface. An approaching train will cause an audible signal to be created. An object on the surface enables the doors to rotate so as to isolate the guideway from the pedestrian area. This guideway isolation enables the train to pass by. No isolation requires the crossing to be treated similar to a station. Detection of passage enables reversion to the crossing mode.

System Supervision

Any abnormal operation requires the system to be shut down and the operating authority to be informed. System startup requires human intervention.

Station Interface

The station will be elevated to vehicle floor height (approximately 0.2 m) so as to identify the guideway area. It will accommodate partial barriers in the openings to coincide with vehicle doors. These barriers serve to inhibit passenger encroachment on the guideway.

Maintenance

Normal maintenance is centred on the vehicle and is carried out on the track. It includes daily battery charging and occasional running shoe replacement. Other maintenance would be the periodic servicing of the air compressor system.

Operations

Because of the short distances between stations, high speeds are not required, the peak speed being about 22 km/h. The overall service level will exceed walking speed under the worst circumstances.

Limits for jerk and acceleration are derived from transit standards. Transit standards must account for the standee; thus in this application, because all passengers are seated, the rider will consider the ride extremely smooth and comfortable.

4.6 The Vehicle

Vehicle Size - A private right of way allows a vehicle to utilize maximum demonstrated speed. This coincides with an off-the-shelf 60 HZ LIM with a synchronous speed of 6.5 m/s. A shuttle system operating at a cruise speed of 6 m/s[1] with a capacity of 400 people-per-hour-per-direction (pphpd) over 200 metres requires 14 seats or passenger spaces. In order to minimize station length, a six- rather than four-seat vehicle is selected. This vehicle is 1.8 m wide. Where space is at a premium a four-passenger vehicle would be about 1.35 m wide but could be as little as 1.2 m in a less generous version. (See Figure 8.)

The minimum longitudinal space per passenger is about 0.8 m, at which point knees touch. A two-metre vehicle provides an additional gap of 0.4 m, allowing easy access to seats away from the door and/or room for carry-ons.

For the operation selected, two cars are the minimum train. For smoothness of propulsion it is required to add two cars at a time.

Running Gear - The shoe configuration and its attachment to the vehicle are primarily dictated by three criteria:

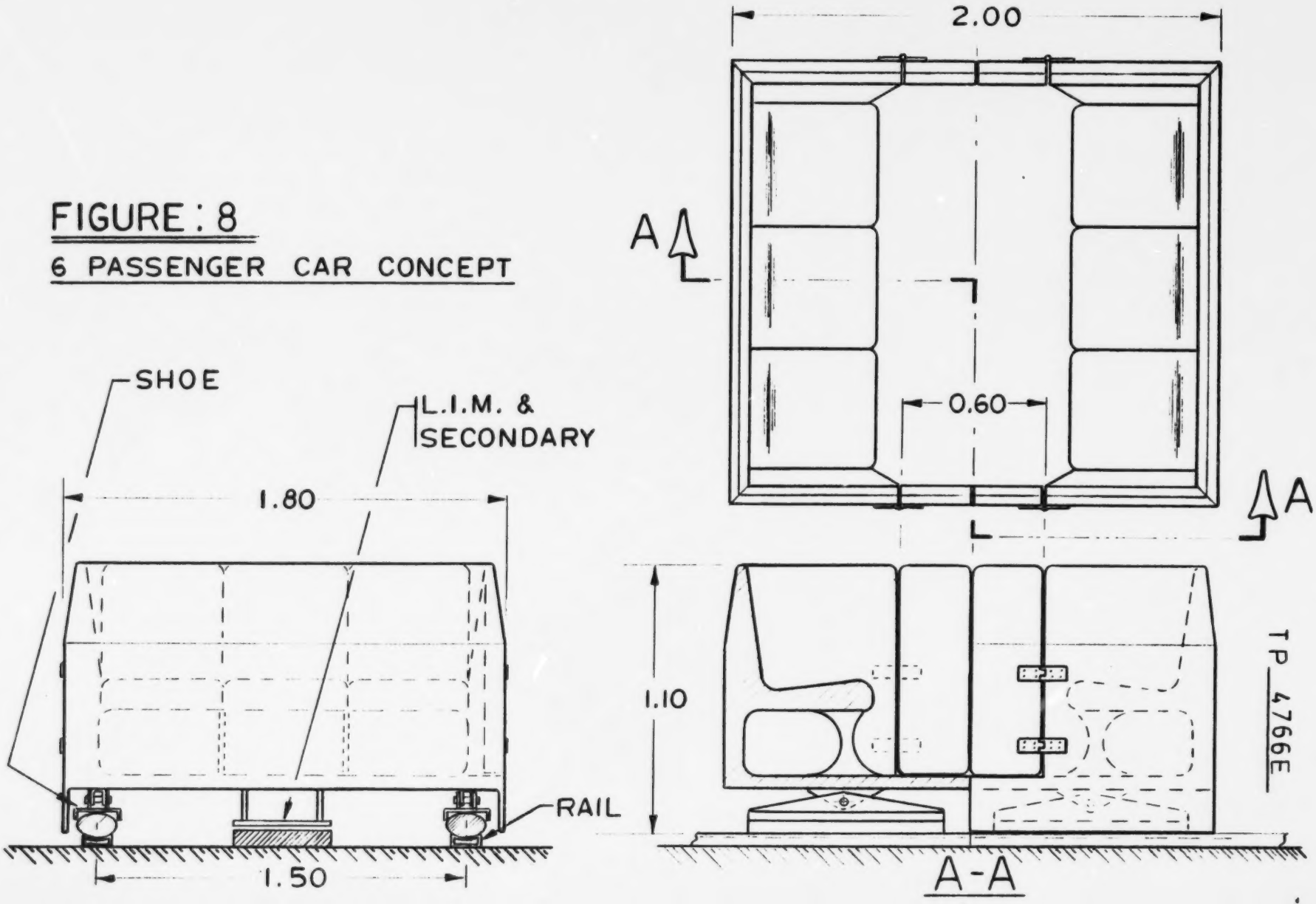
- degree and amount of curvature in the guideway;
- requirement for automatic load-weight compensation;
- maximum gross weight.

Based on performance and structural testing of the shoe, a working maximum upper limit to shoe loading is thought to be about 400 kg per metre of running shoe length. Assuming a vehicle empty weight of 200 kg and a passenger load of 6 x 65 = 390 kg for a gross weight of 590 kg, minimum structural shoe length is 1.5 metres. Space considerations permit up to approximately 4 metres of shoe length.

From the curving analysis illustrated in Figure 16, it is seen that the drag in horizontal curves is comprised of two elements: straight line drag which rises with decreasing shoe length, and curving drag which rises with shoe length and with decrease in radius of curvature. Thus the particular trade-off for best performance is dependent on the actual alignment of the system. For a short section of moderate curvature (say 50 m radius), articulation of the shoe is required and for this application four 0.9-metre shoes are adopted, i.e. the longest articulated shoes which can be physically accommodated. In this configuration any practical vertical curvature can also be readily handled. Thus the suspension allows pitch and yaw while being stiff in roll. In addition, lateral compliance is built in to permit accommodation to track misalignment.

FIGURE : 8

6 PASSENGER CAR CONCEPT



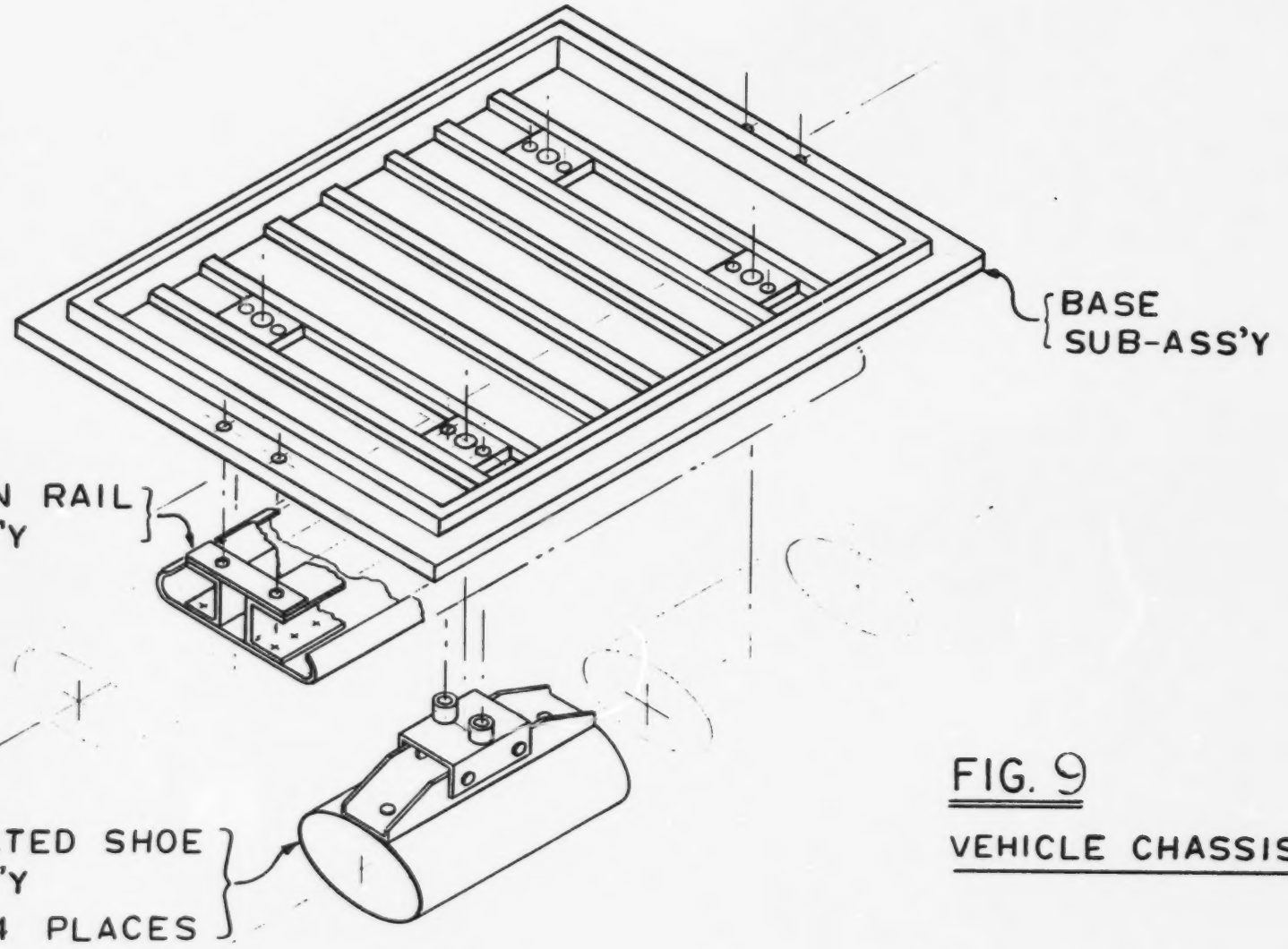


FIG. 9

VEHICLE CHASSIS ASS'Y

There are various design solutions to this set of criteria; however, the one suggested employs off-the-shelf engineered rubber shear mounts at each shoe similar to those shown in Figure 9. This type of mounting accommodates easy removal and controlled vertical stiffness (see Load Weight), and has potential for height adjustment if required.

The thrust characteristic of the linear induction motor is such that as the distance between the two "windings" increases, the thrust decreases. Conceptually it can be seen that if the suspension is elastic a lighter vehicle will ride higher, and therefore experience less thrust.

For LIMs examined, the stiffness characteristics required are approximately linear and of value 400000 $N.m^{-1}$. The shoe itself is elastic but nonlinear with hysterisis and can be considered to contribute approximately 275000 to 350000 $N.m^{-1}$ per metre length. Thus for practical shoe lengths in the range of vehicle size considered the shoe stiffness is higher than required, provided that vertical forces are not excessive. Thus additional elasticity can be added.

Vehicle Structure - For an open vehicle of this size, a body/chassis method of construction is favoured for manufacturing purposes. For a closed vehicle monocoque construction would be preferred.

The chassis can use a large range of materials e.g. welded aluminum frame/plywood cover to a simple one-piece sandwich. For any significant production levels the one-piece sandwich would be perferred. It could be aluminum/aluminum or fiberglass/nomex or any of a range of other materials.

For this vehicle two identical thermoplastic or fiberglass shells, each double, provide the main body. The seats are integrally moulded in; comfort levels are attained by appropriate selection for seat and back rake and length, and cushion design. The shells rest on and are attached to the chassis.

The most significant design question is whether the reaction rail shall be an integral part of the structure or suspended from it. For small vehicles the benefits of an integrated structure are not appreciable, and the design of the reaction rail is simpler if it is separate and adjustable.

The reaction rail must accommodate galvanic action (dissimilar metals), differential thermal expansion, height adjustment, and vertical forces.

When vehicles are joined into trains, the forces are relatively low, and the horizontal and angular freedom required is small, but no slop or looseness in the coupling can be present to generate noise and jerk. The vehicles can be joined at the reaction rails using a simple tow bar, but with rubber bushings.

The greatest detail design challenge is door and door mechanism design. One solution is cafe-type doors, with double-jointed outside hinges, powered by two small linear actuators. This approach can meet the design performance and safety objectives.

The vehicle weight for an engineered vehicle is low. The chassis of a 1.35 x 2 m vehicle including all running gear is computed to weigh about 117 kg. The upper body, in fibreglass or thermoplastic, including seats, weighs about 40 kg. Auxilliaries would weigh approximately 35 kg for a total empty weight of 180 kg for a 6-place vehicle. This is approximately 30 kg per seat, about one tenth of the weight per seat of a typical six-passenger automobile.

The auxiliary systems would include the following items:

- doors and door openers
- battery and charging system
- running lights
- audible signal generators
- door request buttons inside and out
- door closure safety interlock.

4.7 The Guideway

4.7.1

The guideway may be constructed directly on a firm load-bearing floor or on a walkway structure of wood pallet or steel truss girders when the system is applied to the inside environment noted in the Technology Variables of the Operating Scenarios (Figure 10).

Additional variables are reflected when the applications of other options are selected. For example, ballasted or trestled track-way, fully weatherproofed systems and dedicated station systems may be required when "outside" operation is selected. In all cases, it is desirable to provide suitable fencing or barriers around and along the guideway to protect the public and the system. Light chain link or bonded fencing or decorative barrier panels affixed at a suitable distance from the track system to prevent uncontrolled access or obstruction to the moving vehicles are acceptable. It is emphasized that there is no electrical or other hazard and the proximity to moving vehicles is the area of concern. Suitable access areas are built into the system.

Trackage of a specific nature and possibly Linear Induction Motors (LIMs) with proximity sensors make up the remainder of the visible area of the guideway. The motors or LIMs may be totally concealed beneath a covering floor leaving only the concave sections of the rail visible.

The only visible moving parts of the complete system are the vehicles or "cars", which are supported on an air cushion supplied through small, equally spaced holes in the rail. They are moved along by the reaction of the track-mounted primary winding and the secondary winding or "reaction rail" attached to, and concealed under, the cars.

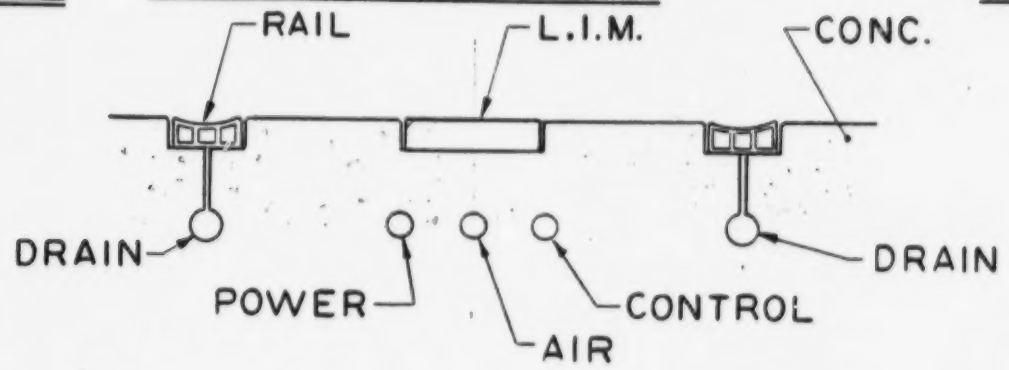
All electrical systems are fully insulated and isolated, providing a completely safe guideway for maintenance and emergency walk-way. A typical section of guideway is shown in Figure 11 (Station) and Fig. 12 (Cross-over).

4.7.2 Elements

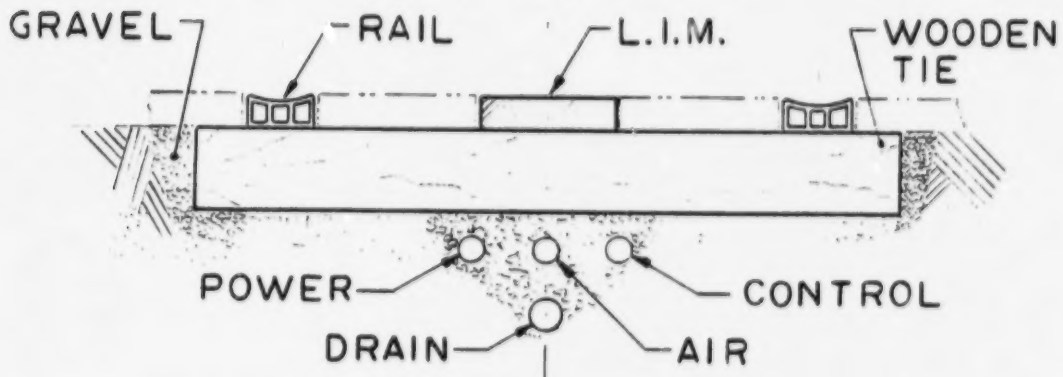
The guideway consists of the following:

Right of Way.
A controlled-access boarding area.
A power-distribution and control room or area.
An emergency control (stopping and starting) system under supervision.
A source of dry, oil-free air to specification.
A vehicle parking area.
Rails and supports.
Linear Induction Motors and support equipment

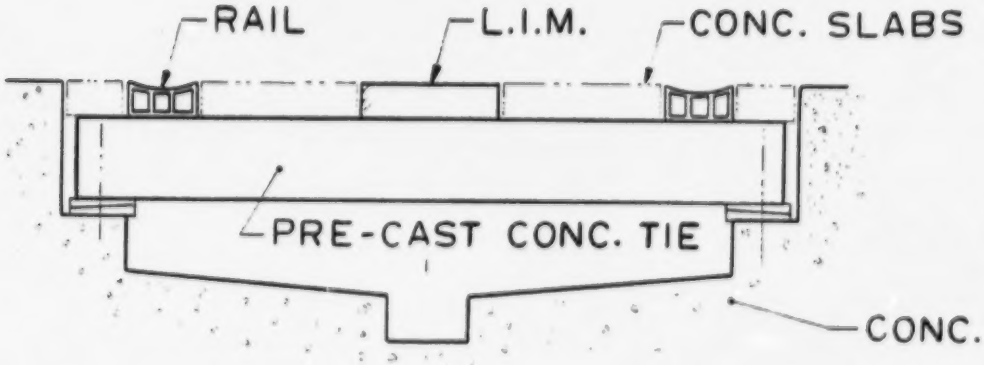
FIG. 10 TRACK INSTALLATIONS TP4766E



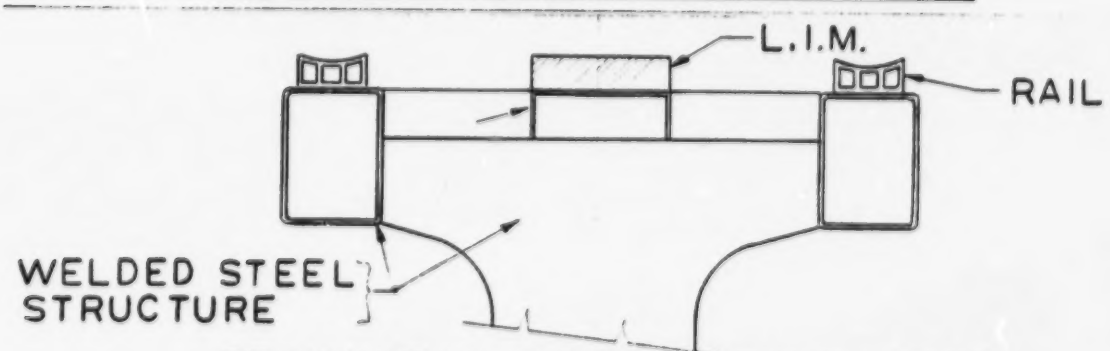
TRACK INSTLN. ON STABLE SUBGRADE



TRACK INSTLN. ON UNSTABLE SUBGRADE



PERMANENT TRACK INSTLN. CONC.



PERMANENT TRACK INSTLN. STEEL.

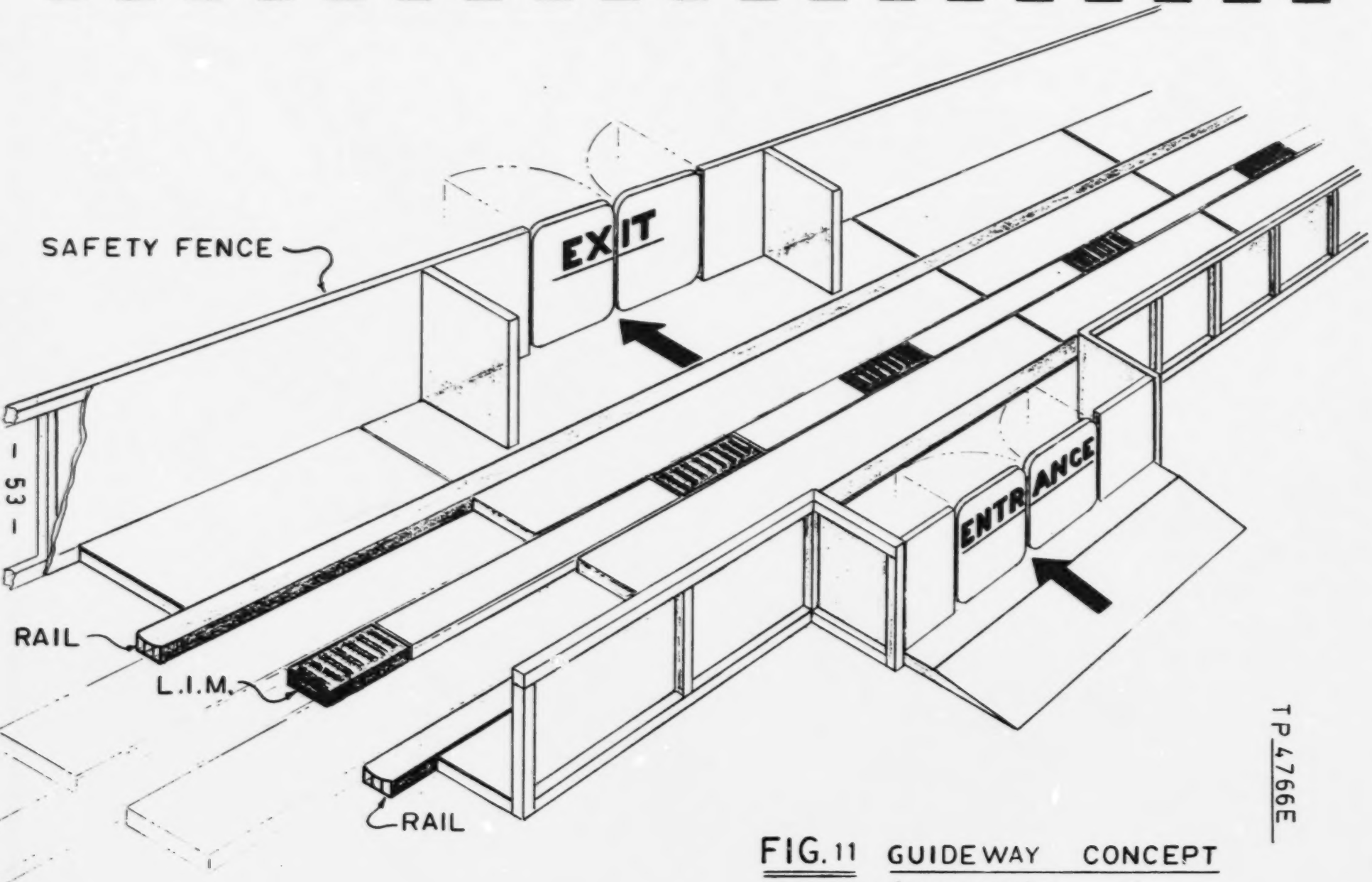
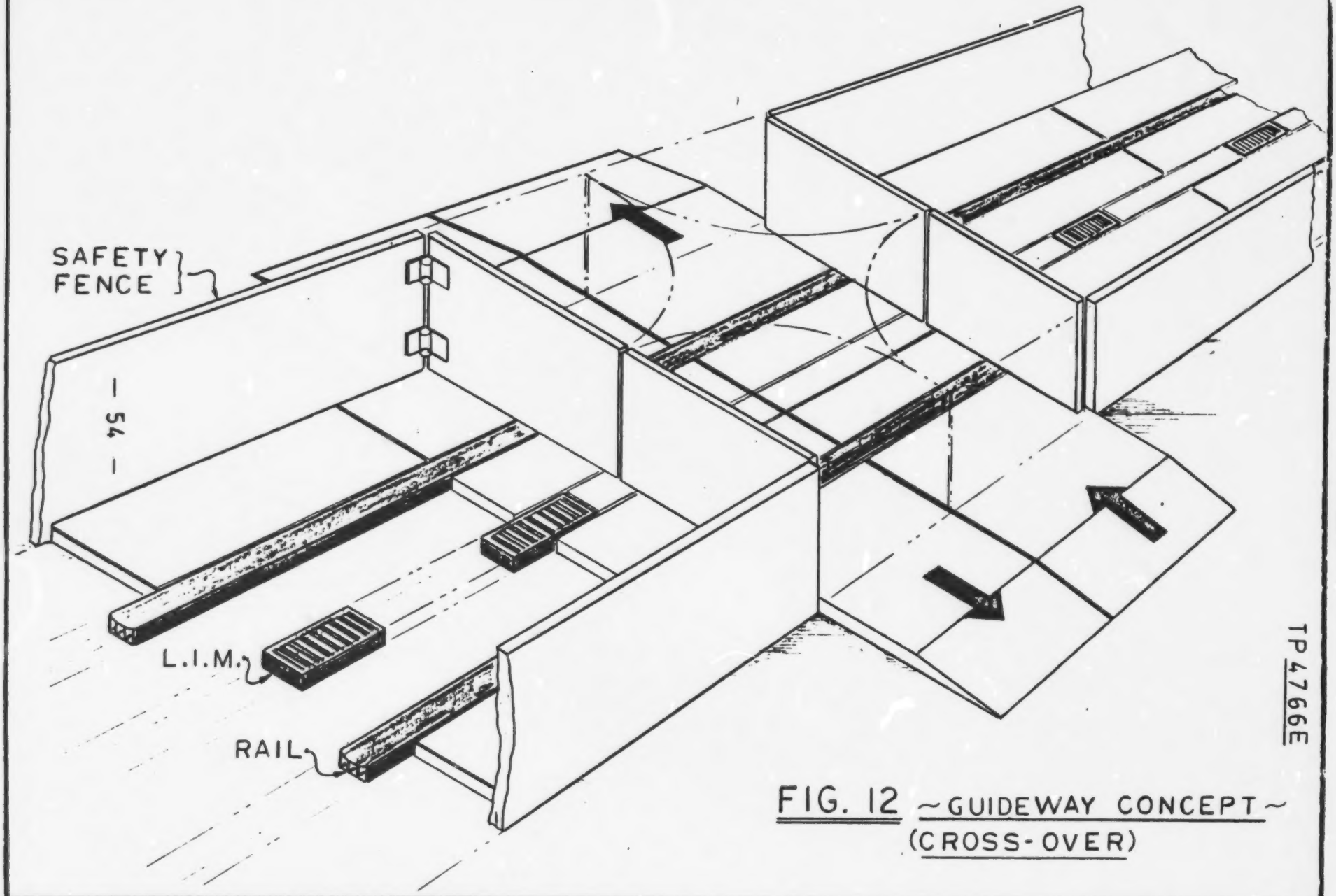


FIG. 11 GUIDEWAY CONCEPT (STATION)

TP 4766E



TP 4766E

FIG. 12 ~GUIDEWAY CONCEPT~
(CROSS-OVER)

- Right of way (R.O.W)

  The R.O.W. may consist of the following:

  - A dedicated walk-way or track way provided by a firm load-bearing-floor such as a shopping centre cement floor or a continuous structure of wood pallets joined together to form a solid unit or a system of interconnected steel truss girders or joists for indoor operation.
  - A ballasted tie-bed or a trestled system capable of supporting the rails, LIMs, emergency walk-way and supporting controls, for outside operation.
  - Linear Induction Motor primary windings and their power supply buried in the track-way.
  - Proximity sensors and/or switches and contracters operated through the train control system.
  - Electrically operated air solenoids, also operated by the train control system.
  - Air supply plumbing, cycled through the train control system
  - Concave surface, anodized, aluminum rails drilled for air receiving and air-dispensing.
  - Wiring conduits or raceway.
  - Surrounding fence or barrier.

- Controlled-Access Boarding Area

This area is capable of funnelling or guiding the passenger(s) to the correct boarding area. It prevents the unwary from accidentally stepping into the path of a moving train by means of automatic gates operated by pressure-sensitive signals or by means of a controlled turnstile.

Visual acceptance by the user public is important.

This controlled access is interlocked with the station propulsion system so that breaching the entry to the right of way will automatically disable the station propulsion system.

Door opening occurs via passenger or rider request by bar or button or treadle, or by turnstile, and sequence is automatic with the door opening only when the car is correctly positioned to coincide with the entry area. Emergency override is provided both on board and in the control areas. This will shut down all power systems and doors may then be manually operated against spring latches.

The entry way is adjusted to the level of the car floor, again providing a visual entry point and providing a "level" entry and egress for the passenger.

A "disabled" system must be re-started by human intervention.

Audible tone warning signals serve to alert the riders and safety attendant, if provided, of an approaching car or of an emergency stop or shut-down.

The controlled-access boarding area usually contains the power-distribution centre and control room but this may be remotely situated if so required.

o Power Distribution and Control

This area may be a part of the controlled-access boarding area for convenience and compactness but may be contained elsewhere with remote switching available to a guideway entry attendant or for a safety system. The remote systems may consist of emergency stop and start controls.

The control system is covered in 4.9 of the Product Section.

Power required for the guideway may be standard 3-phase, 60 Hertz, 208 volt for the LIMs - 600 Volt is preferable. Lower voltage requirements may be supplied by the usual 110 Volt 60 Hertz "house current". This is used for the signal systems and solenoid systems.

A single sub-station or supply station is required and all electrics conform to the Provincial and Federal codes (2) and all items are available "off the shelf".

o Emergency Control System

While all operations including emergency stops are under automatic control, a human-supervised or -actuated stop system is required as is a start system following an emergency stop. All restarts following an abnormal operation shut-down require human assessment/intervention before re-start.

(2) The Canadian Electrical Code - CSA Standard C22-1.

A warning tone will alert the supervision of an emergency or uncontrolled shut-down or "door open" incident. A warning tone also sounds when the system is re-started. A safety or emergency shut-down mechanism is also provided in the car. The control system is discussed in 4.9 of this section.

o A Source of Dry, Oil-Free Air

Dry, oil-free air at a flow of 4.25m^2 (150 CFM) and at a minimum pressure of 138 kPa (20 psi) is required at the bleed holes in the rails.

Current experience with a 29 Kw (40 HP) Rotary Air Compressor together with an air dryer and 545 l (120 gal) holding tank operating at a pressure of 690 kPa (100 psi) indicates that a smaller compressor providing the minimum air flow to a suitable holding tank would be acceptable. The delivered air must be dry and oil-free, and warm enough to ensure ice melting if used outside in low-temperature conditions. Since the low pressures do not present a safety hazard, it is desirable to locate the air holding tank as close as possible to the track supply lines. Because of the noise generated by an air compressor, remote placement with piped-in air might be necessary.

o Vehicle Parking Area

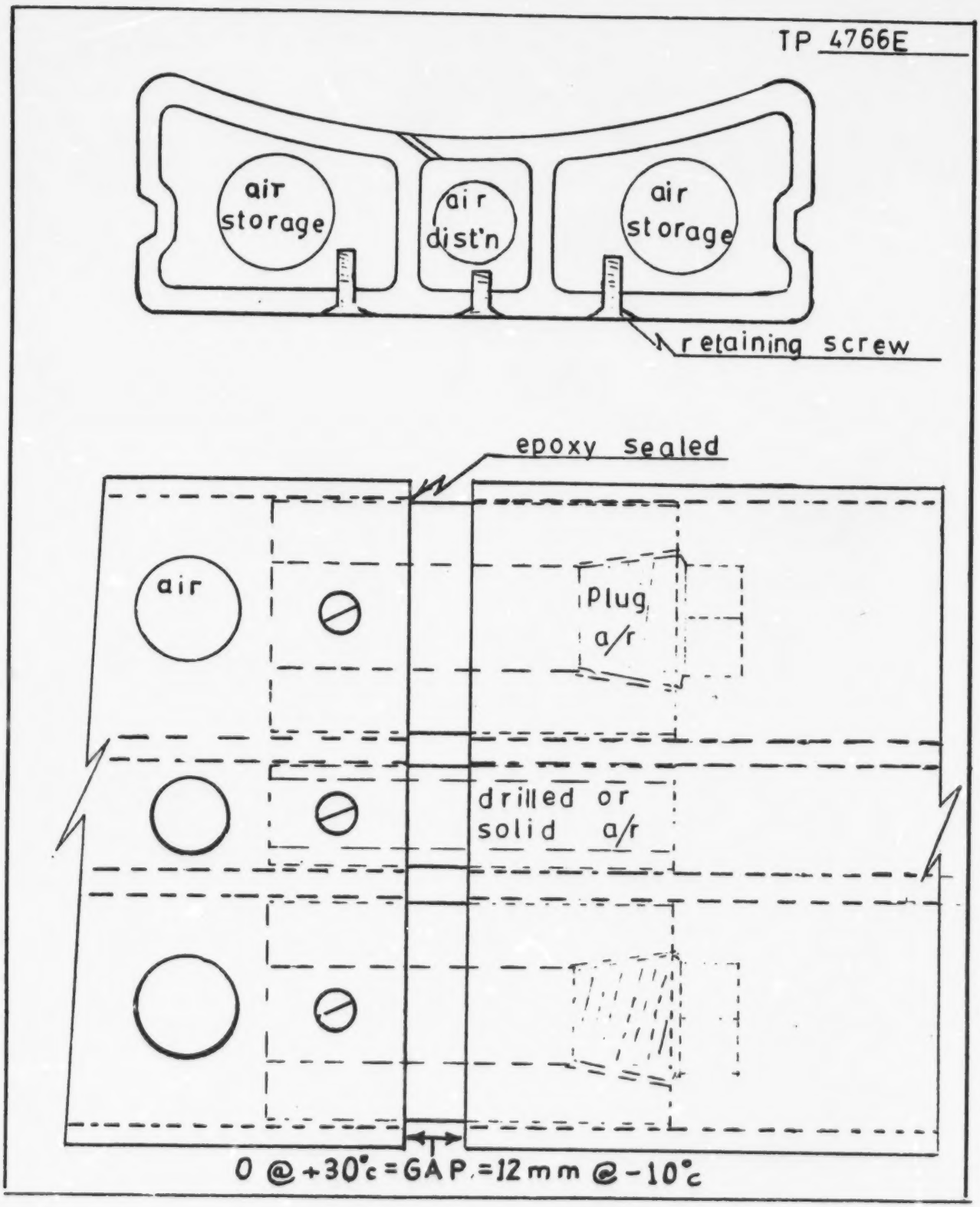
Access to a vehicle parking or storage area is desirable if multiple or spare vehicles are to be provided. Vehicles are run in minimum units of two for smooth operation.

o Rails and Support

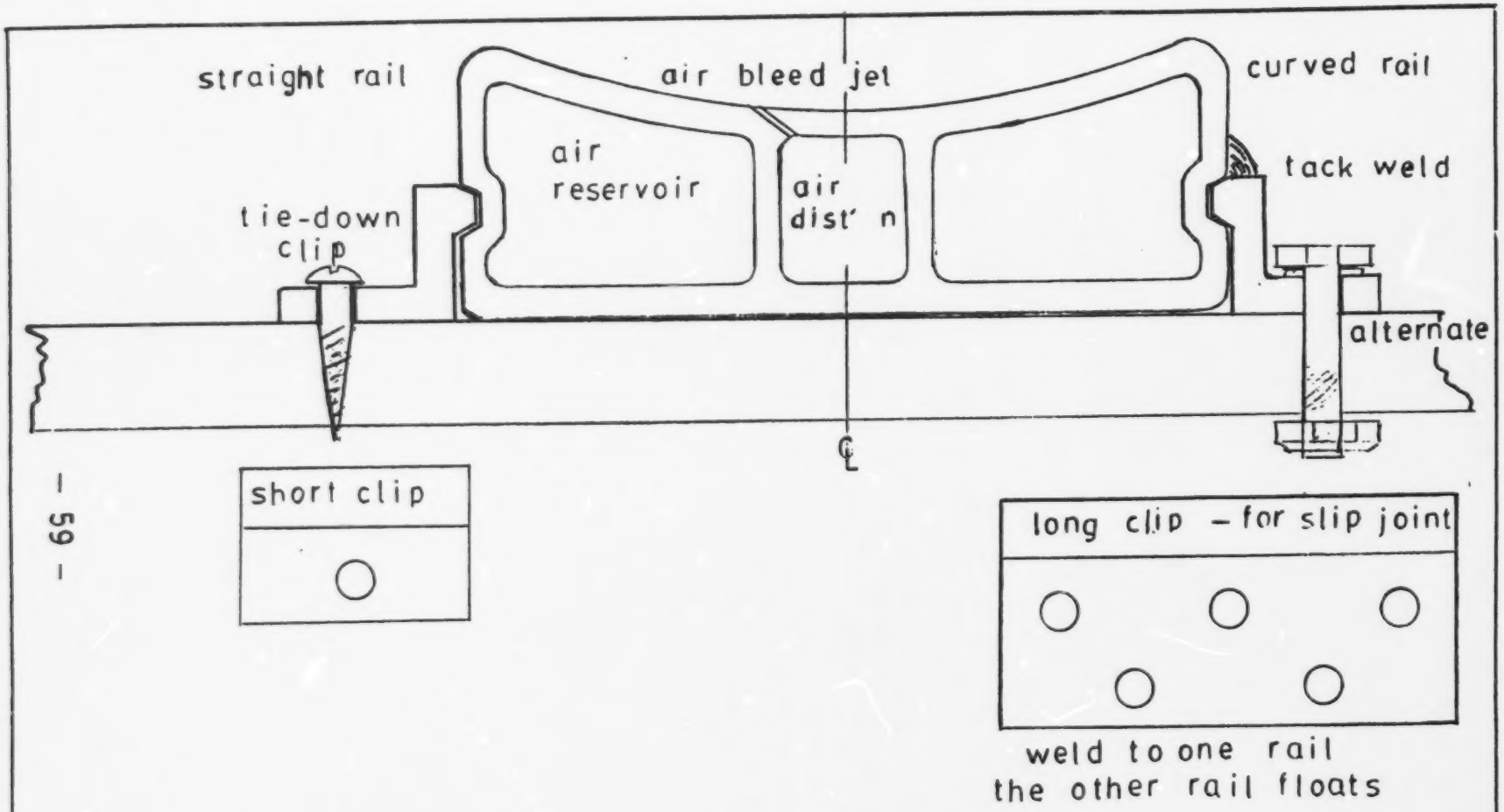
Rails consist of sections of lightweight aluminum extrusions shaped to provide air passages and a curved or concave top surface to provide lateral compliance. The curved section is drilled in a special manner to permit the passage of low-pressure air from the integral central manifold. (See Figure 13.)

The rails are retained to the road bed ties or pallets by small clips and are installed in 15-metre (50-ft.) sections and joined or linked by internal spigots or plugs to ensure alignment. Small gaps in the joint are desirable to permit the expansion and contraction of the rail during changes of ambient temperature. While "indoor" temperatures do not cause any concern the rail expands or contracts about 1 mm for each Celsius degree in temperature change for each 15-metre section of rail throughout the range of -5°C to +15°C. (See Figure 14.)

Track tie-down should be sufficient to meet the safety and expansion requirements and must be well secured in the areas of each LIM to ensure a minimum of variable movement in relation to the LIM. The profile of the rail and shoe diameter as well as shoe length may affect the lift of the air cushion and therefore close attention to control of the rail profile is important.



RAIL PROFILE AND INTERCONNECTION
FIGURE 13



SLIP-JOINT GAP

0 @ 30 °c
6mm @ 10 °c
12 mm @ -10 °c

SECURING RAIL TO BASE

FIG 14

Curving of the track is limited by the shoe size-to-track profile and the payload to be carried.

Experimental experience indicates that a 40-metre curve can be negotiated in a lightweight car carrying 4 or 6 passengers, using a suitably tuned suspension.

o Linear Induction Motors and Support Equipment

Power to move the "cars" is supplied by Linear Induction Motors (LIMs).

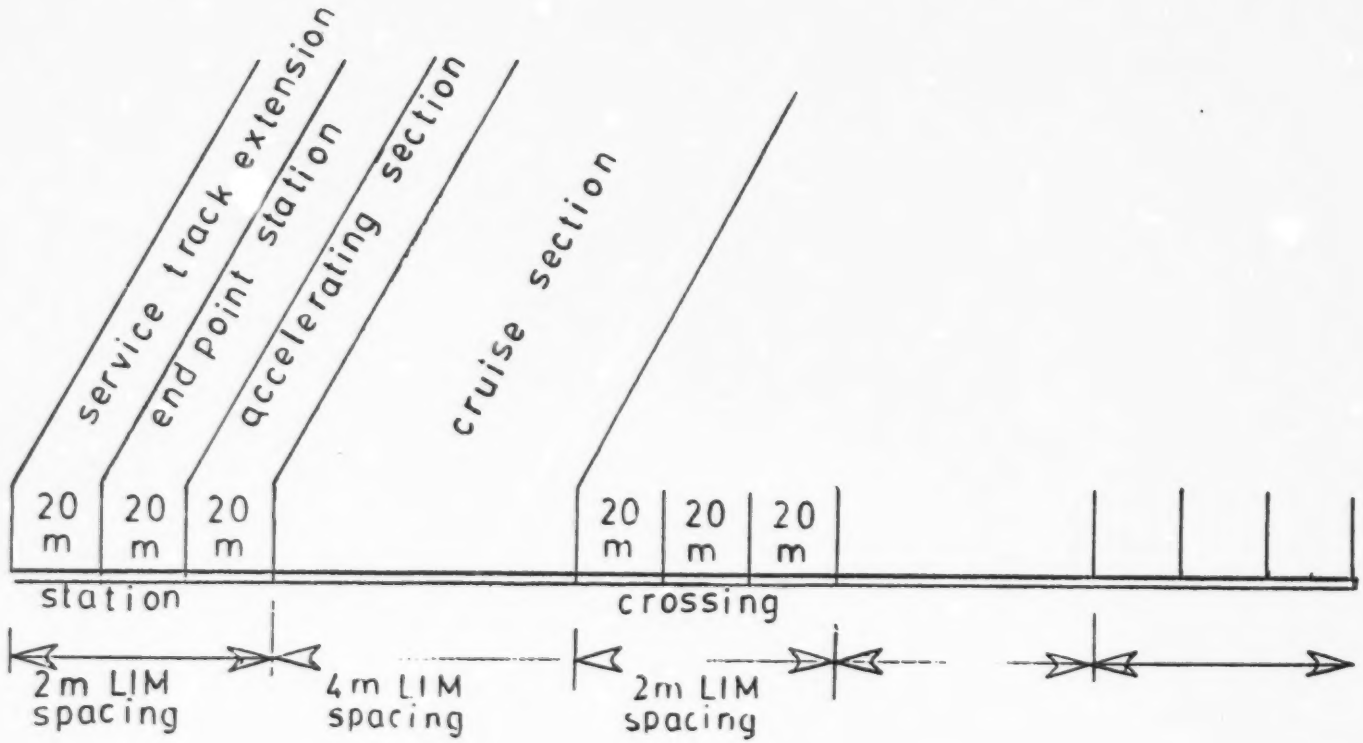
The primary section is somewhat analogous to an "unrolled" electric motor fastened to a supporting structure (Figure 4).

The secondary section comprises a sheet of aluminum 2 mm to 3 mm thick and approximately 38 mm wider than the primary core, backed by a sheet of iron, 3 mm to 4 mm thick (Figure 5).

The primary section is firmly fixed in the floor or guideway and the secondary section is fixed to the vehicle; a minimum airgap of 2 mm is desirable for optimum force and efficiency.

Triggering devices embedded fore and aft of the LIM cause the unit to be "powered up" and "powered down" during the passage of the vehicle, thus imparting a thrust to the vehicle by the secondary section.

Spacing of the LIMs may range from 2 metres or less for braking and acceleration to 4 metres for cruise. A single low-speed shuttle concept is shown in Figure 15. A smooth operation is essential and it is desirable to provide sufficient LIMs to permit the "train" to be passing over one active LIM at any time.



LOW-SPEED SHUTTLE CONCEPT

FIG 15

TP 4766E

4.8 Propulsion

For LIM-in-track applications, linear motors are required with stall thrusts of approximately 600 N and synchronous speeds not more than 10 m/s (Lower speeds are preferable). Both criteria can be met with existing commercial LIM designs; they are 60 Hz, 3-phase 208-volt compatible. The performance specified can be met on the basis of a 10 to 20% duty cycle which is more than adequate for the envisaged use.

The thrust associated with a LIM is a function of the airgap and secondary construction. In general, performance is based on an airgap of 3.2 mm (df 1/8 in), an aluminum secondary of 3.2 mm (df 1/8 in), and a steel backiron of 4.8 mm (df 3/16 in.)

Stall thrust of 175 N to 900 N is available where stall thrust is the thrust at zero speed. For the normal three-phase connection, thrust diminishes with speed to zero at synchronous speed, usually 6.5 m/s or higher. The shape of the curve of thrust-vs.-speed is similar to a cosine. The units are bi-directional and can also be used for braking.

An option for a "cruise" LIM is a 2-phase winding whose thrust characteristic resembles a sine. Such a unit delivers thrust in the direction of motion.

Thrust is proportional to the square of voltage, thus voltage control is a typical method of thrust control where control is required. Passive speed control is merely allowing thrust to balance drag. Variation between trains is a function of the slope of the thrust speed curve.

The synchronous speed is an important system parameter from a control and safety perspective; it is directly related to the supply frequency and pole pitch. Physically there is some latitude to decrease pole pitch in low-power motors; however, efficiency will decrease and sensitivity to gap height is increased. An alternative approach is frequency control. Low-power frequency converters suitable for this application are available off-the-shelf.

The rated power of a LIM is strongly dependent on the duty cycle. The LIM-in-track application is ideal in this respect, in that normal duty cycles are low. A "cruise" LIM duty cycle could be less than 1%, well below normal ratings of 15% to 25% which are thermally based. It can be seen that LIM-on-board schemes are required to oversize the LIM by an order of magnitude or add motor cooling.

The reaction rail requirements are for low electrical resistance, normally met by a sheet of aluminum, and high magnetic flux linkage, normally met by a sheet of iron. Increases in thickness of both tend to improve thrust and efficiency. Variables include variations in thickness of both materials, use of other materials, e.g. copper, use of steel lamination and use of rotor bars instead of or in addition to the iron. Considerable scope exists for optimization for thrust, efficiency

and normal force. For usual configurations the normal force is approximately 10% of the thrust but can be as high as 100%. High normal force (attractive) is a design consideration because it can cause the gap to reduce and lead to striking of the LIM.

At the low powers used in this system, heating of the reaction rail is not a significant consideration, if one takes into account differential thermal expansion of steel and aluminum.

4.9 CONTROL SYSTEM

4.9.1 General

The guideway is divided into three distinct segment types each with a different control strategy. These are:

- o station accelerate
- o cruise
- o station decelerate.

4.9.2 Propulsion Control

The basic building block for propulsion is the linear induction motor with two sensors and solid state switch. The strategy for operation of the LIM is as follows. The first sensor detects the presence of the vehicle and commands the LIM on. In order to conserve energy this should occur as close to the vehicle as practical. The LIM must be on prior to the vehicle's passage in order that smooth thrust transition occurs on the vehicle (no jerk). The sensor will be of an inductive type. If the two sensors are in parallel, the LIM will stay on until the vehicle has passed completely over the LIM. The sensed elements on the vehicle can be the reaction rail or a separate rail.

4.9.2.1 Station Accelerate

The LIMs in this segment always fire in the same direction regardless of the direction of the vehicle, becoming station decelerate in approach from the opposite direction. The making of the door loop "enables" the entire propulsion system. A current limiter assures a smooth, low-jerk buildup in initial thrust, based on time-programmed current buildup. This segment is entirely sequential in operation and does not sense or respond to discrepancies in performance.

4.9.2.2 Cruise

The cruise segment is reversible, controlled by one reversing contactor. Operation can be sequential in nature, reversed upon detection of the last LIM off. Speed control is passive in this region, relying on the characteristic of the thrust-vs.-speed relationship of the LIM and passive load-weight compensation. Speed variations due to weight are considered inconsequential in this type of operation.

Options include a LIM with a single-phase winding.

This LIM has two advantages: it does not need to be reversed since thrust is always in the direction of travel, and the thrust-vs.-speed curve is steep near synchronous speed, minimizing speed variations. The disadvantage is that thrust is zero at zero speed, and the vehicle would not start up from zero speed. This characteristic may however be considered an advantage in that unsafe start-up is prohibited.

4.9.2.3 Station Stop

It is proposed to use a positive feedback control system during braking. Advantages include:

- Equal brake rates regardless of weight (and thus stopping distance).
- Failure of a small number of LIMs can be accommodated readily.

This approach may be inexpensive because:

- Two sensors at each LIM enable a speed calculation to be performed.
- One voltage controller may run the entire segment.

Thus, the vehicle will enter the station at a controlled low speed (less than 1 m/s). Final positioning will be handled passively by allowing the vehicle to glide into a segment of track with no air. Under this condition, brake rate is independent of weight.

A number of other passive braking options were considered to have potential for development. A promising method requires LIMs with a low synchronous speed (less than 1 m/s). While physically the options for building such a LIM are limited, the equivalent effect can be achieved by supplying the segment with reduced-frequency three-phase power, using a single low-power solid state converter. The vehicle would undergo regenerative braking in this configuration. One advantage of this approach is that the vehicle is powered into the station. Design problems to be overcome include:

- Requirement for reversing contactor.
- Difference in braking rates for vehicles.
- Low acceleration in reverse direction.

One concept which merits investigation is the use of permanent magnets in the track to effect the primary field. While certain system disadvantages are present, the opportunity is provided for completely fail-safe braking.

The control strategies presented are feasible and will meet system operational requirements.

4.9.3 Air Control

The normal operation air is not supplied to the entire system but only to those sections in which the vehicle is present. The track is

divided into 15-m sections and normally a maximum of two sections have air on at any time. The availability of sensors at each LIM and standard air control components render this sequencing operation feasible and straightforward.

In addition, control of air is used to provide emergency braking at the stations. With air off, the braking rate will be 1.5 m/s^2 regardless of vehicle weight. This is a substantial but comfortable braking rate. At the station and its approach, the track sections will employ "energize on" air dump valves. Thus air is provided if the propulsion system is working. Any loss of braking power will cause the fast-acting valves to "dump" air from the system. The spacing and timing will ensure that a vehicle will come to rest at the station or prior to entering the station.

4.9.4 Jerk and Acceleration Control

Jerk and acceleration control strategies are different in the different control zones. The baseline objectives are:

Jerk 1 m/s^3

Acceleration = 1 m/s^2

In general, the smoothness of the propulsion using LIM in track is achieved by careful LIM spacing as a multiple of train length. The relationship between thrust and reaction rail position is predictable. Particular care must be paid to transition regions. For seated passengers, acceleration levels of 5 m/s^2 are not uncomfortable provided that jerk is not excessive. Thus in the uncontrolled acceleration section propulsion levels are set to achieve 1 m/s^2 for a loaded train. A train with one passenger may experience acceleration as high as 2.5 m/s^2 with no load-weight control and this is considered acceptable.

Station to Accelerate - Jerk limited by thrust control device.

Accelerate to Cruise - Accept very low force level change.

Cruise to Braking - Jerk limit algorithm on controller.

Braking to Station Entry - Jerk limit algorithm on controller.

Station Entry to Stop - Mechanical jerk limit.

While a number of options are available in the control system for normal and emergency modes, and the final logic and interlocks remain to be designed, a safe and reliable control system is feasible and practical.

4.10 CURVING ANALYSIS

4.10.1 Straight Line Friction

The development work carried out by E.B. Eddy and UTIAS has revealed the cellular nature of the lift under the shoe. At each end of the shoe the pressure is non-uniform and tends to zero at the exposed edge. For "interior" cells bounded by air injection holes the pressure and thus lift is considered uniform. As the shoe moves down the track the end regions vary as a proportion of the overall length of the shoe depending on the relative position of air jets to shoe end. We can, however, average the lift and hence resulting drag, using the following assumptions:

- Drag for no air is the dry coefficient of friction, typically 0.15; end cells have this value.
- Drag for a uniform cell is 10% of this value, typically 0.015.

This results in the following expression:

$$K_f = (0.1 \times k_{dry}) + \frac{((L \times n - 1) \times 0.1 \times k_{dry} + 1 \times k_{dry})}{\frac{L \times n}{2.0}}$$

where K_f = Average Friction Coefficient at normal operating pressures and shoe loadings
K_{dry} = Dry Coefficient of Friction
L = Shoe length in metres
n = No. of holes per metre of track

The results for polyethylene shoes/anodized track with $K_{dry} = 0.15$ are plotted on Figure 16.

4.10.2 Contribution Due to Curving

The shoe is considered to be rigid in bulk, with local deflection where heavy contact is experienced. Thus a shoe contacts the curved rail at the centre on the inside of the rail and at both ends at the outside of the rail. This results in the following:

- A loss of lift, and hence increase in drag due to non-uniform gap, and hence non-uniform pressure distribution.
- A "squeeze" effect on the shoe material caused by the straight shoe being force-fitted into the curved track. This locally overcomes air-bearing action, causing high local friction.
- Distortion of the vehicle suspension geometry in the curve allowing side forces on the shoes. These are reacted by direct rail contact rather than air-bearing action.

Order of magnitude analysis of these terms yielded the approximate curving contribution to total drag shown in Figure 16.

4.10.3 Total Resulting Drag

The result of the two contributions is that for a given curve radius there is a minimum drag associated with a particular shoe length. It should be noted that selection of this length may unduly penalize a total system if it results in extra friction at all parts of the track.

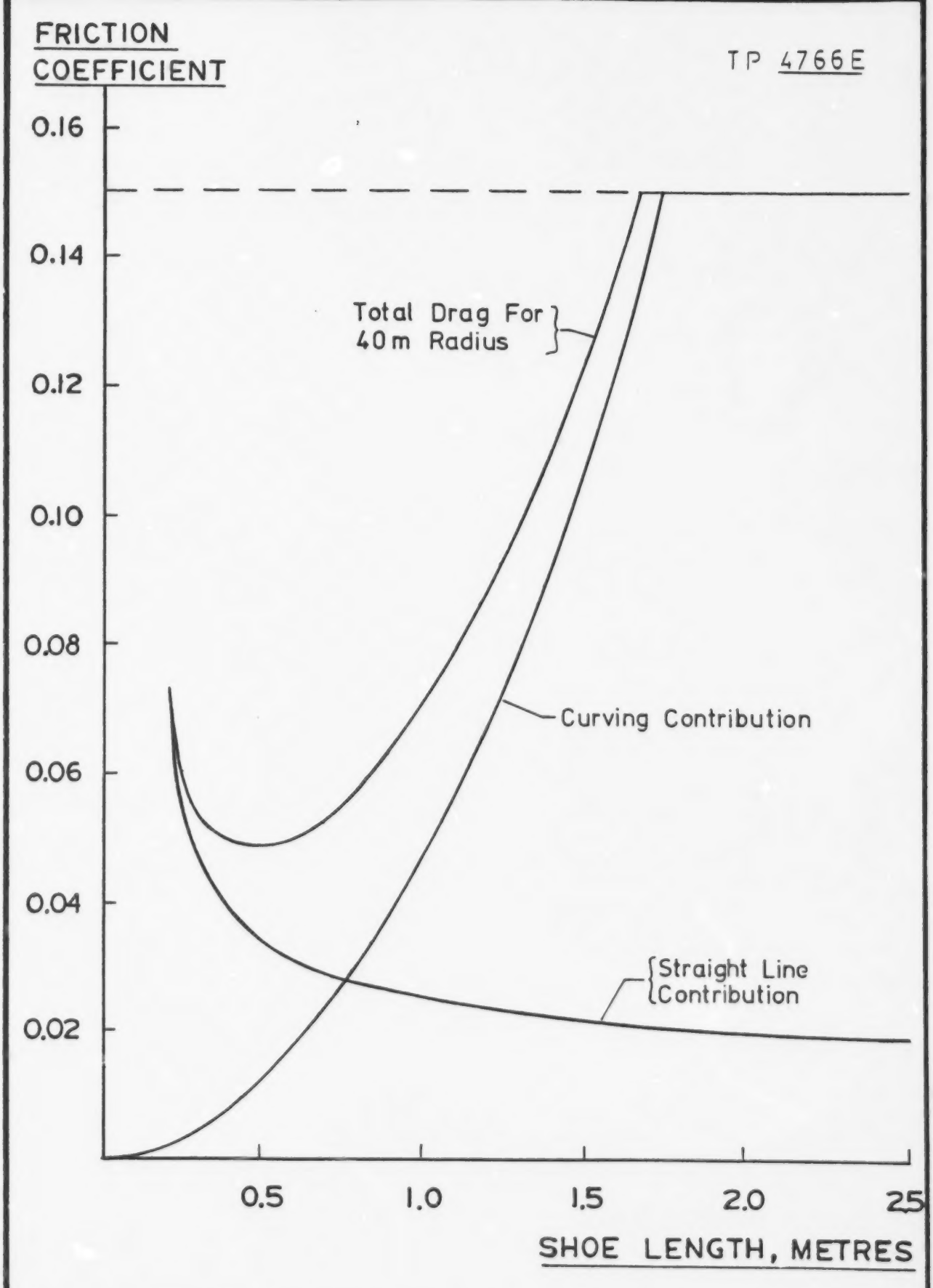


FIGURE 16 - FRICTION IN CURVES: ORDER OF MAGNITUDE ANALYSIS

4.11 COST

The cost of an installation is site-specific and operation-specific. This section has identified the cost elements and their associated cost including that of installation. The elements are derived from the requirements of a system as described in section 4.5.

In developing the cost of a system it is found that most component elements can be associated with three distinct categories:

- Station
- Guideway
- Vehicle

A key variable is inside/outside installation, thus two distinct cases are developed:

Inside: On an existing floor or base

Outside: Includes supporting structure construction

Some key elements are functions of additional and multiple variables.

Air Supply: Length of Track, Number of Trains, Requirement for Redundancy

Power Supply and Control: Number of Stations, Length of Track, Number and Size of Cars

Linear Motors: Length of Track, Number of Stations, Length of Trains

The cost review was based on 1981 construction costs identified in "YARDSTICKS FOR COSTING", published by Construction Data Systems and Southam Communications, and corrected for average inflation rates to 1983. This was supplemented by actual costs of specific materials used in preliminary experimental application. The estimate was based on an average of the "Canada-wide" "high" and "low" estimates.

Note: Compliant air bearing cost information, for purposes of confidentiality, has been supplied under separate cover.

5.0 RESULTS

In order to carry out the evaluation it was necessary to focus efforts on one system. The system selected coincides closely with the requirements of the interior application at Toronto International Airport (TIA).

Capacity requirements for TIA could be met by a double shuttle using short trains of six-passenger open vehicles. The double shuttle is required at this length to provide an adequate service level.

Based on the cost factors identified in 4.11 and assuming a conservative car cost of $10,000, the cost of a single shuttle with two termini and 3 crossover stations is estimated to be lower than competing systems and of the order of one half of moving sidewalk costs of $8,000 per metre.

Until a final system is fully defined and demonstrated the cost estimates will be tentative. Nonetheless the first estimates are favourable when compared with competitive systems.

The application is most favourable to the technology and there appear to be no significant technical barriers to the implementation of such a system. There remain significant questions pertaining to:

- shoe and track wear
- operating performance over time
- system reliability and availability
- cost implications of final design solutions
- safety of final design solutions

The curving performance of the technology limits curvature to a 40-metre radius or more for a small vehicle. Smaller radius curves imply power consumption penalties over the entire track. Very short radii of curvature can be accommodated, but would require special purpose-designed mechanisms.

For increasing capacities, loops or switching are required. Fundamentally, switching performance can be related to curving performance. Switches, especially turnback switches, are inherently simple in concept, but are of significant size because of the large radii of curvature on the transfer portion.

For other applications the number of questions multiply:

- How will the system cope with ice, snow, rain, dirt, etc.?
- How do the required tolerances and environmental effects impact on guideway, especially in "green-field" applications?
- How would driver control be accomplished?
- What is the maximum operational speed?
- What type of train control system is required in a loop operation?
- What is system energy consumption?

- Can control systems be devised which allow unlimited pedestrian access to the guideway?
- What is the actual curving performance of the vehicle?
- How important are track and profile tolerances?

The conclusion of the work is that the technology is feasible and potentially inexpensive. Combined with the quality of the service in terms of comfort, noise and ride, the result is an extremely attractive transportation system.

Preliminary experimental testing indicates that the questions raised for exterior applications can be resolved with favourable results and this leads to a recommendation to proceed with a detailed study of the remaining questions to evaluate them and to provide full confidence in the expanded concept.

6.0 CONCLUSIONS

6.1 The results of the study provide the following conclusions:

- The powered SailRail technology is applicable to many areas in the transportation industry.
- The nature and visibility of the concept provide a major attraction point and not just "a means of transportation".
- The powered SailRail concept is competitive technically in all areas of the defined system operating requirements.
- The SailRail concept appears to have several advantages over conventional forms of vehicle levitation and power drives.
- The relative simplicity of the guideway and vehicles renders the system superior to other forms of public transportation.
- Since maintenance is centred on simple vehicle parts replacement, and a passenger control system, the concept should enjoy a favourable acceptance with operators.
- The Market Study has uncovered a wide range of potentially attractive applications in low-capacity intra-building and inter-building mobility.

7.0 RECOMMENDATIONS

7.1 In assessing the ability of SailRail to accommodate the applications noted in the Market Study, an experimentally-based program is required to determine and verify the technology and performance limits. This should include wear, curving, speed, practical issues and outside performance.

7.2 The study has postulated certain strategies for control and its implementation which reflect on cost, safety and reliability. The design, construction and testing of an integrated system will determine and verify the overall assumptions, costs, and performance.

7.3 The study has been significantly aided by the fundamental work previously accomplished. It is recommended that:

- Further detailed work be carried out to better understand the fundamental mechanisms of this air-bearing technology with special consideration given to out-of-alignment conditions including curved-track phenomena and switching performance under real-time conditions. This work has identified opportunities for accomplishing the objective.

- An experimental program is recommended to develop improved curving capabilities and performance.